A case for the student researcher: Expanding the role of undergraduate research in the professional formation of engineers

Kathryn M. Youngblood, Julie R. Roseberry, Aubree L. Van Winkle, & Nicola W. Sochacka
College of Engineering
University of Georgia
Athens, USA

Linda Vanusupa
College of Engineering
California Polytechnic State University
San Luis Obispo, USA

Carol J. Thurman
Center for Serve-Learn-Sustain
Georgia Institute of Technology
Atlanta, USA

Patrice A. Torcivia Prusko
Harvard Graduate School of Education
Harvard University
Cambridge, USA

***Abstract*—This paper examines the role of social inquiry as a bridge between education and practice for undergraduate student researchers in engineering. Prior work has demonstrated the efficacy of undergraduate research (UR) as a tool to increase retention rates, particularly in STEM disciplines, and to encourage progression to graduate school. However, little work has been conducted on the role of UR in the development of professional skills for engineering students. Among such skills, the ability to work in complex socio-technical systems is a critical competency for professional engineers that is often under-addressed within a standard technical curriculum. In this paper, we used collaborative autoethnographic techniques to recall and reflect on three students' UR experiences working with a methodological approach, SenseMaker, which is designed to investigate emergent patterns and behaviors in complex, social systems, such as the systems involved in educating engineers, as well as those systems that engineers work with on a daily basis. The contributions of this paper are threefold. First, we found that using autoethnographic techniques to individually recall and collaboratively write and make sense of UR experiences facilitated the construction of novel insights of both personal and broader significance. Second, we found that providing undergraduate engineering students with the opportunity to systematically inquire into a social system served as an intellectual bridge between their highly structured and theoretical core engineering courses and the complexity of engineering in practice. Third, inquiry into the specific system of engineering education, in which the students themselves are important participants, provided students with an opportunity to experience, first hand, the value of meaningfully engaging all participants in a system, as they will be required to do as engineers working with non-engineers in their future professional roles. All three of these contributions point to a potentially much broader role of UR in engineering education as a way to further enhance the holistic professional formation of engineers. Collaborative systems inquiry within engineering education research can be a small-scale laboratory that allows students to develop problem solving skills within complex systems, while the empowerment of student researchers to study and improve their own education systems can simultaneously yield innovative perspectives in research.**

Keywords—undergraduate research, social inquiry, professional skills, complex systems, research ethics

I. Introduction

The value of undergraduate research (UR) to STEM education has been well documented, highlighting an array of benefits such as increased student retention rates and improved science communication skills [1]. However, much of this work aggregates student experiences from across all STEM fields, with a particular emphasis on traditional sciences (the "S" in STEM), a practice which can be problematic for understanding differential benefits across various fields [2]. Differences between STEM fields are especially relevant for professional fields, like engineering, that primarily seek to prepare students for real world career trajectories rather than progression to graduate school. Thus, investigations of UR that focus on outcomes directly relating to an academic track, such as obtaining graduate degrees and co-authoring papers, are perhaps not as applicable measures of success for an engineering UR program as they are for degrees in the sciences. Post-graduate outcome expectations for most engineering students are different from other STEM fields. As a result, many characteristics important to professional development and engineering identity, such as communication skills, leadership abilities, and high ethical standards [3], have not been sufficiently examined as potential benefits of UR within the broader STEM literature. Moreover, prior studies show that faculty, too, seem to regard and value UR principally as a pathway towards developing into a scientist [4]. The explicit goal of many UR projects is, in fact, the development of a "science identity", the student's perception of themselves as a scientist [1]. Students, however, often see their UR experiences as more broadly contributing to their development as problem solvers and critical thinkers [4].

There is no doubt that UR has shown great promise as a tool for encouraging students to pursue graduate degrees and helping traditionally underrepresented students self-identify as developing researchers in various fields [5]; some work has pointed toward the utility of UR experiences in improving retention rates of women in engineering programs [6]. But, overall, relatively little prior work has been conducted on UR experiences for engineering students. Futhermore, those engineering UR experiences that have been studied tend to focus on technical research rather than on *socio*-technical systems and the skills that are needed to thrive in such systems,

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such as the ability to communicate with diverse members of the public and collaboratively problem solve in team settings. One likely reason for this focus is that the bulk of research opportunities available to engineering undergraduates are technical in nature. It seems to be a common model that undergraduates participate in such research to support the technical research program of a faculty member, and/or as credit for an engineering elective, or as part of a technically-driven senior thesis [7]. One study which did examine the impact of technical UR experiences on teamwork and leadership skills found no statistically significant effect on these skills over typical professional development curriculum given in the classroom [2].

It is possible that the lack of focus on non-technical skills in undergraduate STEM research indicates that UR is simply not as applicable for professional degrees like engineering. Or, perhaps apparent discrepancies between traditional UR experiences in engineering programs and desired outcomes of professional growth for engineering students present an opportunity for engineering educators to think more expansively about the role of UR in the holistic formation of engineering students. In this paper, we share student reflections on an UR experience in which they were invited to design and test a novel approach to understanding, and ultimately changing, their local, social system of engineering education. Their reflections point to the value of expanding UR experiences beyond technical domains.

II. Context

A. *Learning about SenseMaker*

The research project that provided the context for this reflective paper was first proposed at an NSF-sponsored, 2-day workshop in April 2017. The purpose of the workshop was to introduce approximately 30 members of the engineering education research community to a novel approach, SenseMaker, a narrative-based, participatory research methodology that enables the capture and analysis of a large quantity of stories in order to understand complex systems and how to change them. The purpose of the workshop was to explore potential applications of SenseMaker for engineering education.

Grounded in complex adaptive systems theory, neuroscience, and anthropology [8], the stories collected in a SenseMaker study provide a live snap-shot of the complex system under investigation:

"…in the same way that many pixels come together to produce a clear image. SenseMaker® can also assist with early recognition of weak signals of changing social dynamics, and with the identification of emerging or outlier factors that deviate from normal trends and patterns" [9].

One important way in which SenseMaker differs from traditional research methods is that participants, not researchers, ascribe meaning to their own stories through a process called self-signification. Quantitative analysis and visualization of these interpretations enables the identification of "adjacent possibles" in the system—areas of potential shifts where researchers and participants might collaboratively design and introduce small, "safe-to-fail probes" (small-scale experiments) in order to promote more of one type of micro-narrative and less of another. SenseMaker has been previously used to investigate a diverse range of settings, such as young girls' experiences in Rwanda [9], safety issues at a Canadian electric utility organization [10], and concerns over potential conflict in the Korean Peninsula [11]. We refer readers who wish to learn more about SenseMaker to http://cognitive-edge.com/, which contains case studies, concepts papers, and descriptions of basic methods, among other resources.

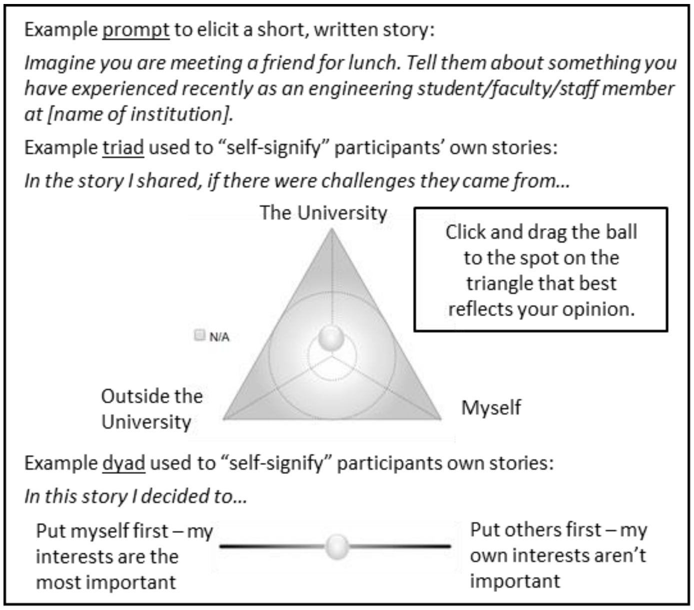
Over the course of the workshop, the facilitators introduced the multiple steps involved in designing a SenseMaker study, from instrument design, data collection and analysis, to the design and implementation of interventions to shift the dynamics of a particular social system in a desired direction. The student reflections in this paper focus on the first step, instrument design, of a SenseMaker study.

B. *Challenges in designing our SenseMaker study*

At the workshop, the facilitators encouraged the 30 or so participants to design multi-institutional studies that share a common data collection instrument, or "signification framework" (see Box 1 for example elements of such a framework). Four faculty members (the last four authors of this paper), took up this charge and decided to design a multi-institutional study based, at that stage, loosely around the idea of investigating diversity in undergraduate programs, for example, how diversity manifests across various factors (ethnic, socio-economic, ways of thinking etc.), and how it is supported or not supported by institutional cultures and practices. Following the workshop, the four faculty members met regularly via videoconference to continue the design of their study. In the course of these meetings, they decided to base their signification framework on the concept of thriving [12], as this theoretical construct seemed to intersect across each of their individual, institutionally-situated, research interests. Further, they chose to study not only the undergraduate experience, but the experiences of all members in the social system of interest, that is, undergraduate and graduate students, as well as faculty and staff.

Following the instructions given by the SenseMaker workshop facilitators, they began their instrument design by reviewing the literature on thriving (see Box 2, adapted from [13]). They also worked with SenseMaker personnel to clarify functional requirements for the prompt, triads, and dyads (see Box 3). This process continued over several months, until they observed that their work was not progressing at the rate they thought it should be. Somehow, their instrument design had hit a roadblock. The prompt felt like it was going round in circles and the triads were similarly just not "making sense." It was at this stage that the faculty members recalled the "participatory" nature of the SenseMaker approach. And so they took a step back from their regular meetings and shifted towards a student-faculty collaborative model, located primarily at a large state university in the south eastern United States and involving the first three authors of this paper. The project soared. Prompts were carefully pried apart, put back together again in novel ways, then tested, re-written, and re-tested. The literature on thriving was reinterpreted from the perspective of undergraduate students, and similarly reconfigured into new triads and dyads. As the student-faculty partnership progressed, two things became clear. First, the quality, or validity, of the signification framework increased in ways that would not have been possible had the four faculty members pushed through without the input from students [14]; and second, the students involved in the instrument design derived benefits from this UR experience that seemed to extend beyond benefits typically acquired in more traditional, technical UR settings.

Box 1. Two example elements of our SenseMaker signification framework



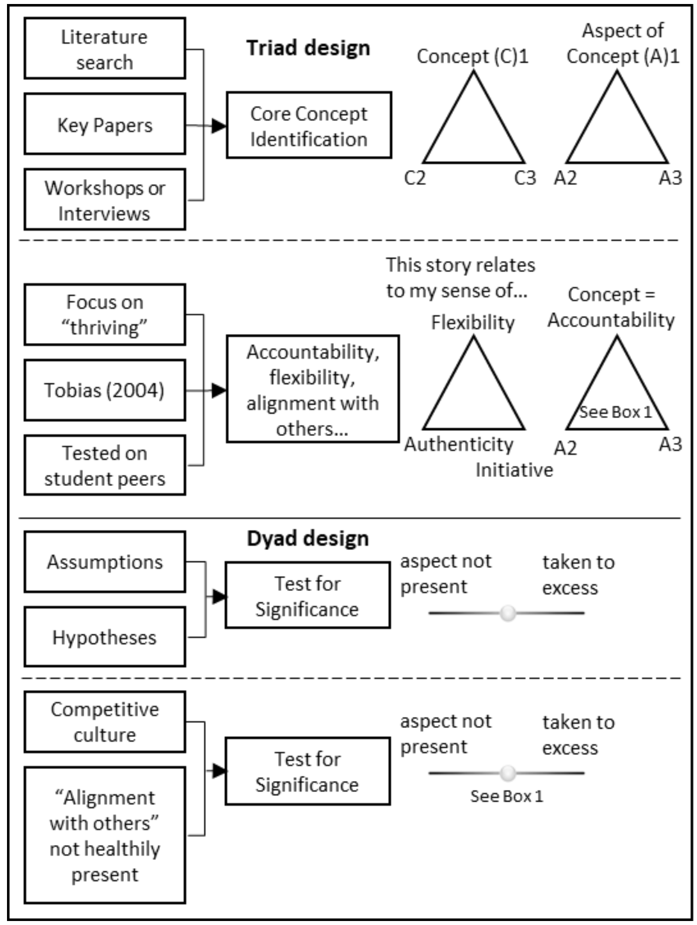
III. Methods and Methodology

The data for this paper comprise three collaboratively developed student reflections, or narratives, which describe the first three authors’ UR experiences in the SenseMaker project discussed above. From a methodological perspective, these reflections are inspired by prior work in the area of autoethnography (AE) [15], where authors write detailed accounts of “epiphanies”, or “ah-ha” moments, they perceive to have had a transformative effect on their life or thinking . In line with Carolyn Ellis’ work on evocative AE [16], in the following section we present a set of three:

“stories that create the effect of reality; celebrates concrete experience and intimate detail; examines how human experience is endowed with meaning; is concerned with moral, ethical, and political consequences; encourages compassion and empathy; helps us know how to live and cope; features multiple voices and repositions readers and “subjects” as coparticipants in dialogue; seeks a fusion between social science and literature . . . and connects the practices of social science with the living of life.” (p. 699)

Then, in line with Leon Anderson’s approach to analytic AE, we use these co-constructed narratives as “empirical data to gain insight into some broader set of social phenomena than those provided by the data themselves” [17]. In our case, the social phenomenon we focus on is a type of UR experience that, we believe, has the potential to more holistically contribute to the professional formation of engineers (see *Discussion* section).

Box 2. Process of using literature to design the signification framework



Box 3. Example functional requirements for an effective prompt

1. Elicits a micro-narrative that is personally relevant and grounded in a real life experience of the respondent;
2. Enables the respondent to choose a story of any emotional tone (i.e., must not overly prime and influence the respondent’s choice);
3. Elicits a micro-narrative that indirectly relates to the focus of the study (i.e., must not direct the attention of the respondent to the focus of the study);
4. Is not hypothesis-driven;
5. Avoids cognitive overload for the respondent. (i.e., is succinct);
6. Is conversational, experience-generating; and,
7. Elicits a description, not an evaluation;

IV. Collaboratively Developed Narratives

A. Julie: Prompt Development

I was first introduced to SenseMaker when I began undergraduate research during the fall semester in 2017. I was in my fourth year of studying mechanical engineering, and I had just returned from a 3-month civil engineering internship with a non-governmental organization (NGO) in Indonesia. Beginning this design process with SenseMaker proved to be a challenging experience as it reshaped my preconceptions of a typical research study. At the same time, it was satisfying, because it provided a framework to make connections between my engineering classes and the experiences I had in Indonesia.

The challenging part of the process began the first time I was introduced to SenseMaker. I remember my head spinning as I attempted to process everything about this new approach and contribute to the discussion in useful ways. This feeling tended to be the pattern for most of the fall semester, especially when Kathryn, Aubree, Dr. Sochacka, and I were developing the prompt for the SenseMaker survey. At one research meeting I recall struggling to understand the "functional requirements" of an effective prompt, e.g., that it must not be hypothesis-driven or directly address the topic of discussion, should not explicitly invite respondents for a positive, negative or neutral response, should be personable, relatable, and experience generating, and elicit a description—a personally-relevant non-fictional story—rather than an evaluation (see also Box 3). These parameters struck me as quite different to what I thought of as a typical approach to research, where one usually starts off with an initial hypothesis and then collects data to test that hypothesis. As a result, my mind was stretched in this meeting as we evaluated variations of our own prompt as well as prompts developed by research groups from other universities against these criteria.

As we critiqued eight or so of the prompts, none of them seemed to meet all of the functional requirements. One of the easier ones for me to process, due to its simplicity was, "Your best friend is thinking about studying engineering. Tell them about something you have experienced at [name of university] that you think is important for them to know." At first, this prompt sounded like it met the requirement of being personable and relatable. As we analyzed it more, though, we thought it might be *too* personable and risk eliciting more of a positive response, because the person was speaking with their "best friend," who they may even be trying to convince to come and study at the same college! Also, we wondered if the word "important" might prompt the telling of a more evaluative rather than an anecdotal story. So, we went back to the drawing board and reviewed the wording of the prompt extensively. As an engineering student, I had never known words to carry so much meaning. Finally, with much stress and strain, we landed on, "A friend of yours wants to study engineering. What would you tell them about your experience in the college of engineering at [name of university]?" We worked in a similar way with three other prompts, before finally deciding to bring them to the table in the larger research group. My mind was drained and I was in desperate need of a nap after a long day of classes and discussing word choices. It was not until a few weeks later, after many more perplexing moments, that the purpose of this process—of putting so much time into choosing our words—finally clicked.

Another method we used to deepen our understanding of SenseMaker was studying other surveys previously conducted. I was assigned to compile all of the triads, dyads, stones, and prompts I could find that were publicly available. As I was doing this, distinct components of the SenseMaker surveys triggered memories of experiences I had in Indonesia during my internship. My mind went back to when I went with the non-profit's survey team on motorbikes through jungles and rice fields to collect data to design and distribute rainwater tanks. We not only met with government stakeholders and influential community leaders, but we also sat for hours in each home to build a relationship with the members of the village. I wore pants in 100-degree weather, made a conscious effort not to use my left hand, and sat crisscrossed swatting at mosquitoes buzzing around me day after day. We shared food and drink with each other, exchanged jokes and stories in their language, and listened to their interests and concerns. I held back tears as they shared heartbreaking stories of their children, parents, cousins, or other close relatives and friends who had fallen victim to dirty drinking water. We considered methods they had previously tried and mapped out strategic locations to place the tanks throughout the village for the households that wanted them. One could undoubtedly see the benefits of this community-centered approach compared to other organizations' strategies, as their water systems were often left to ruin simply because they had not gotten to know the people they were trying to serve. As I continued to study more and more prior SenseMaker studies, I realized that SenseMaker is a tool used to do a similar method—to better understand and learn about a system from the participants' perspectives, rather than taking over with our own thoughts, "words," and hypotheses.

Another thing that resonated with me about SenseMaker is that it is both qualitative and quantitative. It elicits personal stories of individuals while collecting quantitative data on how those individuals interpret their stories. It connects statistics with people. Complexity and different facets of a system are being accounted for through the stories, while the survey (triads, dyads, and stones) allows for substantial quantitative data as it interprets the stories to observe a lot more of the system than is possible from the stories alone. However, bridging these kinds of gaps between qualitative and quantitative, the individual and the system, researchers and non-researchers, is still incredibly difficult. Shane Elson, the director of the NGO I interned for, wrote in a reflective blog, "Sometimes building bridges across government, culture, and language when both sides struggle to see the full potential of the 'what is possible' is frustrating. Learning to communicate a common vision relevant to each side based on culture and language is as difficult as it is necessary."

This same tension lies within analyzing systems at home. Take, for example, the end of semester surveys I am asked to complete for each course I take. Most of the time, the questions are irrelevant, a bit strangely worded, or annoying to fill out. I also have no idea what my responses are used for—I don't hear many of my professors tell me that they made improvements to courses based on them and I wonder if it is a waste of time to even take the surveys. If students could be more involved in this evaluation process, like writing the questions and seeing the responses, the process would probably be much different. This type of participation and focus on the system is what SenseMaker seems to be aiming for. It provides a method of putting oneself inside of a system to benefit all members to serve an entire community justice. Each person has their own experiences and "language," which may not be the same as fellow classmates, coworkers, or other participants in a system. This is why we seemingly over-analyzed the phrasing of our prompt so much and why this process has been difficult and frustrating at times. Yet, knowing the possibilities of the outcome of this survey makes the endeavor worth it.

B. Kathryn: Translating Literature to the Framework

As a final semester senior engineering student, I've been drawn to research throughout my undergraduate career. I know I want to practice engineering as an environmental consultant, but the idea of being a professor one day also appeals to me. So, I have tried to get involved in as much research as possible during the last four years. However, like most engineering students, my early impressions of research were as a strictly quantitative exercise. For example, my first research experience involved using a Doppler current profiler to record and model tidal flows in a coastal estuary. The experience was no doubt interesting, educational, and rewarding; I got to go out in the field and deploy the technology in a coastal estuary in the southeastern United States and later fit the data to a model of tidal flow to understand seasonal tidal change. But while this experience began to shape my identity as a developing researcher and scientist, it was not exactly what I would call revolutionary in its effect on my perception of the world.

Working with SenseMaker falls into a different category. While I had been exposed to systems theory in some of my classes, the technicality and rigidity of scientific research seemed to "control" for complexity, i.e., remove dynamic feedback and emergence from the equation and, instead, frame events in terms of cause and effect. The SenseMaker approach, as a novel method of social inquiry, is so inherently reliant on the researcher's thorough understanding of complex systems, and so heavily founded in the theory of how change in such systems occurs, that it has forced me to re-explore my own understanding of these ideas and has bred new insights into complexity in the engineering field.

Systems thinking resonated with me when I first read about the concept in a classroom setting, but it had remained in a box of philosophical ideas I thought unlikely to have a role in my work as a student researcher—or even much as an early career engineer making small design decisions. SenseMaker provided a way for me to take these ideas off the shelf and put them at play within a real system. Specifically, in this project I have been heavily involved in translating the literature into the SenseMaker survey instrument (see Box 2). Although SenseMaker relies on the process of "self-signification," wherein participants interpret their own narratives, it requires the research team to first generate a signification framework in which this meaning-making process occurs. The design of the signification framework is the one opportunity the researcher has to "draw a (systems) boundary," so to speak, around a specific topic of interest; thus this step is quite critical.

As noted above, our study is grounded in the concept of thriving. Prior research in the field of organizational psychology shows that just as characteristics that contribute to "thriving" at the individual level have been identified, similar organizational characteristics make for a thriving social system and, in turn, contribute to the thriving of individual members [12]. I found reviewing the literature on this topic quite fascinating. Intuitively, I felt the characteristics discussed, such as autonomy, accountability, and initiative, to ring true to my own experiences, and I accepted and internalized the theories presented without much critical thought. As a stereotypically goal driven, Type A personality, it was easy to integrate these somewhat rigid ideas of what constitutes "thriving" into my own notions of what it means to be successful, perhaps because they fit with character traits that have been ingrained into me growing up in a Western culture and education system. The deeper level questions would come later when we attempted to translate these established theories of thriving into triads as part of our signification framework.

As I worked on developing the triads, overall the theory fit well with the context of engineering education and the proposed study focus, but we still had to make tweaks along the way, not only editing wording so the language would better serve our intended audience of students, faculty and staff, but also tweaking and adding ideas within the thriving parameters themselves to better fit our understandings of the realities of an engineering education system. For example, during discussions within our diverse research group, we felt the characteristic of "internal alignment" sounded rather lofty; so we brainstormed synonyms such as integrity, authenticity, and consistent values. Similarly, "alignment with others" was translated to concepts such as mentorship, collaboration, and community engagement in the engineering education setting. We also included the characteristic of self-confidence in one of our triads to serve as a proxy for self-efficacy and perceived personal development, which we felt were crucial metrics of institutional success in a collegiate setting that were not captured in the theoretical thriving framework.

This translational process, which was facilitated by our diverse group of students and faculty with different experiences in the engineering education system on which we were focusing, brought up questions I had not thought to ask during my original reading of the literature on thriving—from what system were these findings generated? Can you really generalize the qualities of a thriving organization such that they are applicable to fit all types of organizations? Can you even create a definition of thriving to begin such a process, one that remains true across different value systems and cultures? No doubt, the theory of thriving we found in the literature served as a critical starting point for our own signification framework. However, our own experiences within our institutional setting led us to make changes and adapt the generalized guidelines, even adding our own parameters of interest in some cases. For me, the process of bringing theory back to the ground level in a unique, changing social system served as an important reminder that the true "experts" in a complex system are those who experience the day-to-day realities of that system. Theories from academic experts serve as excellent guidelines, but—as engineers and as researchers—we cannot hold on so tightly to theory or best practices that we are unwilling to adapt to the reality of a changing, complex social system.

In fact, utilizing such "best practices" as strict guidelines breaks with the theory of complex systems in which the SenseMaker model is grounded. During the course of working on this project, I had the opportunity to attend a workshop in which Dave Snowden, the creator of SenseMaker, emphasized that complex systems are just that—complex—and even so-called "experts" can be misled. Conversely, complicated systems possess enough order that they can be understood by careful study; influencing change can therefore be dictated by models of good practice (see Fig. 1). In complex systems, however, change occurs too rapidly for this model of simplification to be effective. The "pulse" of the system can only be taken by garnering input from many members, and emergent properties inherent to complexity make small, safe-to-fail experiments the best way to nudge the system toward change (see Fig. 1).

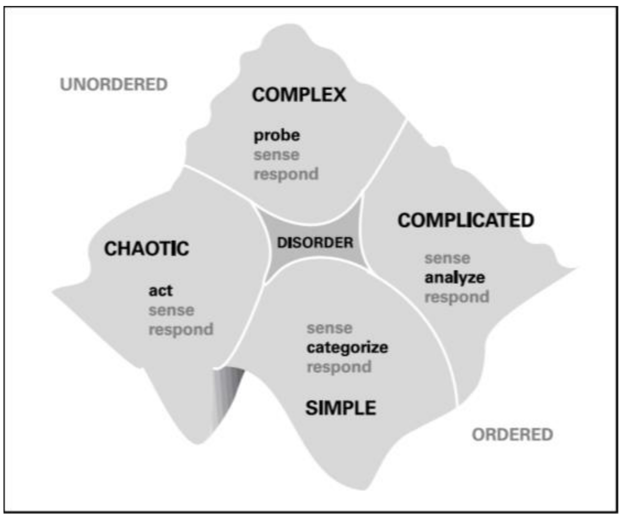


Fig. 1. Model depicting how change occurs in simple, complicated, complex, and chaotic systems [18].

As engineers, we spend much of our undergraduate careers learning when it is safe to make simplifying assumptions, when we can ignore dynamic forces and assume static equilibrium. However, the reality of a complex system is that it is never stationary, and the reality of social systems is that they are never simple, and rarely even complicated. These social systems are as much a part of engineering projects as physical systems are, but it was not until this undergraduate research experience that I had significant exposure to learning the methodologies to address complexity. There are many engineering problems I have already encountered in my very early career and internship experiences for which I cannot rely on simplifying complexity; rather, in dealing with complex social systems, I must lean into a spirit of experimentation, being flexible and willing to change.

C. Aubree: Building Bridges between the Classroom and the Real-World

Running from my last class of the day, I hopped onto a bus that would hopefully take me across campus just in time to make my 4 o'clock research meeting. Today, Kathryn, Julie, Dr. Sochacka, and I would be piloting what we had been working on for the past few weeks—the first draft of our signification framework, which entailed a prompt to elicit a micro-narrative, and then a set of triads and dyads for participants to self-signify their narratives. The prompts we developed were all essentially asking the same question, but each involved different phrasing and diction in an attempt to elicit true-to-life participant responses that reflect the reality of the system in question, as opposed to prompting participants to respond to a predetermined hypothesis that the researcher believes to be a problem in the system. The meeting would hopefully narrow down our prompt ideas into one useable format that we could then employ for our first larger pilot study.

I pushed open the door, only to find that it was locked—typical—and I had to wait until I was let in so we could begin the meeting. I sat down and opened my laptop to begin taking notes as our research group discussed our project and began passing out a prompt to each of the ten or so people around the table. Every person, including Kathryn, Julie, Dr. Sochacka, and I, was handed different variations of the prompt, and asked to write a story based on what emerged for them in response to the prompt. I received the following prompt and answered it with the first thought that occurred to me upon reading the question, trying not to write what I knew was the response we were looking for: "A friend of yours wants to study engineering. What (short/brief) story about your time in the College of Engineering would you tell them?".

After about 5 minutes, we stopped writing and asked for the group's comments and prompt responses. Surprisingly, everyone had written very different responses to what we thought were fairly similar prompts. Some answered with a short narrative, others with a broad statement, and still others with a list of advice for future students or faculty, all depending on how they interpreted their prompt. Slight diction changes seemed to encourage very different interpretations and responses and almost all members of the research group had critiques and suggestions to offer. This feedback was really quite surprising, as we thought we had a very solid prompt narrowed down and that the minor wording differences wouldn't make as much of a difference as they did. This experience really served to open my eyes to the idea that everyone applies meaning to different words based on their individual perspectives. In my engineering classes, I typically encounter situations with only one, or very few, "right" answers, and so to see such varied responses coming from multiple people in the research group about practically the same question was astounding. Did that mean that I had been viewing my classes wrong? Were they not truly preparing me for the "real world"? These varying viewpoints were sure to appear in everyday interactions in engineering careers, so why was I only seeing the differentiation now? The answer, I would come to realize, is that engineering classes themselves are designed not as a comprehensive view of a complex system, but as a piece of a complex system. As I sat around the table listening to the varying feedback from my peers and professors, I realized that just as our classes are a key holistic system component, so is undergraduate research and peer connections. In addition to these pieces, I also recognized another crucial part of my education that acted as a bridge between the classroom and the real world: my co-operative experience with a large power company, during which I worked for the company for three rotations adding up to an entire calendar year. In school, you are typically told that what you learn will be applicable to your job, but while that may be true in some cases, in my experience, it was not. I did use concepts from my classes, but my learned mathematical and scientific knowledge was not utilized. The job itself was mainly about making customer connections, and designing the best electrical systems to feed projects that were both cost-efficient and customer pleasing. I realized that engineering is not always about numbers and figures, it's about interpersonal skills and the ability to recognize and solve problems efficiently and ethically.

Sitting at the research table, listening to everyone's varying feedback on the prompts, all three of these components finally tied together to form a more comprehensive and holistic view of engineering: my classes, my co-op, and finally, my undergraduate research. The research was my tool to bridge the gap between the scientific and calculated tone of engineering classes and the interpersonal, relationship-heavy and unpredictable engineering career outside of the classroom. Research was a mixture of both of these ideas, it was both unpredictable and grounded in science. I could finally connect these two very different sides of engineering, and I realized that collaborative research is more valuable than serving as a platform to higher education, it is a platform to higher comprehension.

V. Discussion

As presented in the narratives above, we found that using autoethnographic techniques to individually recall and collaboratively make sense of UR experiences facilitated the construction of novel insights of both personal and broader significance. Although the narratives depict three diverse perspectives, each with different personal interpretations of key lessons learned during the UR experience in engineering education, all suggest that the experience of performing meaningful, engaged social inquiry as an undergraduate engineering student has the capacity to deepen understandings of complexity when problem solving in systems that involve people–as most engineering problem solving does.

Julie's narrative, in describing her experience of drafting the prompt for the SenseMaker survey, discussed how SenseMaker stands apart from other survey methodologies and drew comparisons between the research setting and her "real life" humanitarian engineering internship in Indonesia. Drawing parallels between methodologies used in this engineering education UR experience and non-profit work within socioeconomically disadvantaged communities in Southeast Asia, Julie's narrative highlights the importance of immersing oneself within the system in question in order to achieve meaningful understanding and "do justice" to the community. Careful attention to wording and social cues that may initially seem irrelevant to engineering success became critical keys to engaging with the community in question and gathering necessary information, for both research and design.

Kathryn's narrative examined similar understandings of the need for collaborative engagement with the social system in question, although her narrative was centered on a different piece of the research design process. Her narrative, which described translating the literature around organizational thriving into a framework for the SenseMaker survey tool, reaffirmed that a research approach grounded in collaborative problem-solving works within models of how complex systems undergo change. By the very nature of such continuously evolving systems, it is difficult to fit a theoretical model to a complex system. Experts in a complex system are those in the system who experience its everyday reality.

For Aubree, UR served as a bridge between the engineering classroom and her internship experience. Through her narrative on piloting the first draft of the signification framework in the research group meeting, Aubree described coming to an understanding that there is no one right answer to an experience in a complex system. Like Julie, Aubree focused on an increased awareness of the power of words and interpretation. Her narrative argued that undergraduate research is not just a part of higher education but, in her experience, a platform to higher comprehension of complex systems theory and its applications.

Together, the collaboratively developed narratives canvas several key takeaways that demonstrate student learning and development of professional identity as engineers through the UR experiences. Although housed within the context of a SenseMaker research project, the student narratives describe the construction of an intellectual bridge between highly structured core engineering courses and the complexity of engineering in practice that stems from the nature of social inquiry rather than the particular details of the project in question. Each narrative described "aha" moments in which the students encountered novel perspectives and new understandings of complex systems through inquiry into a social system. These insights apply not only to research, but also to the work within complex systems students will likely encounter as future engineers. The narratives depict working in a collaborative research setting as a mechanism for connecting "classroom" experiences with the "real-world," both in the team-oriented and iterative nature of the process, and in the focus on communication that is all too often left out of engineering classrooms. The UR experience of inquiry into a complex social system–one of which the students are themselves members rather than outside consultants–expanded perspectives of what skillsets are needed to be a successful engineer in our modern, complex world and served as a practice arena for utilizing such skills in order to further develop a professional identity as a future engineer.

Prior work has established that UR is a beneficial experience for undergraduates in terms of student retention rates, scientific reasoning, and progression to graduate school. However, the exploration of how skills developed during UR experiences can be transferable to a professional context has been quite limited. The accounts presented here focused extensively on how experiences in social inquiry were applicable to prior professional experiences and conjectured how such a skillset would come into play during future work as an engineer. Although the student authors of this paper are all deeply involved in improving their college through research, they are, first and foremost, developing engineers, and it is in this role that they have found the application of complex systems theory most useful. These collaboratively developed narratives are intended not to characterize a typical experience in UR for an engineering student, but rather to provide an in-depth exploration of the benefits of collaborative social inquiry for these students, thereby providing insight into the possibilities of utilizing UR as a tool for professional development. Further research on involving engineering undergraduates in academic research, including–and perhaps especially–other forms of social inquiry, is needed.

Concurrent to limited exploration of domain transferable benefits of UR that this paper has sought to address, little work has been done to examine benefits of collaborating with undergraduates as research professionals with valuable perspectives to share; such exploration is especially relevant to engineering education where students themselves are often the subject of study. Prior work does indicate a direct connection between ethical research practice and overall research quality. Framed as a process of "ethical validation," this work suggests that seeking to "do justice" to all members of the research process (e.g., participants, co-researchers, and readers) has the potential to create not only more positive and empowering experiences for all involved but also point to novel ways to investigate social phenomena [14]. Application of complex theory is not only relevant for engineers; it can also serve as a revolutionary model for engineering education researchers wishing to improve their own problem-solving abilities within an educational system. In this context, the shift towards student-faculty collaboration that empowered student researchers as "experts" stimulated the development of the signification framework. For engineering educators, student researchers can provide novel insights into their own educational realities, thereby both supporting and improving research and intervention efforts. The insights presented in the student narratives centered on the need to engage with members of a system in order to understand its nature and implement improvements; such insights are as applicable to faculty as much as they are for developing engineers. Engineering education research, therefore, stands in a position to provide students with training in an important set of professional skills that are typically not the focus of their technical curriculum, while at the same time utilizing the unique insights of students into their own educational realities to improve both the efficacy and ethical grounding of research propositions. Much as the principle of people-centered design [19] has been touted for its potential to improve engineering work through refocusing this work on those it is intended to serve, collaborative, student-driven social inquiry in engineering education can yield novel insights.

In this way, an undergraduate research experience in engineering education can serve as a microcosm which allows students to experiment with problem solving in a complex socio-technical system and to develop the skills that are needed to thrive in such systems. Simultaneously, because researchers themselves are implementing collaboratively based social inquiry methods and empowering members of a system to create change within their own educational institutions, they are both modeling methods of working in complex systems to their students while applying principles of people-centered problem solving that will ultimately produce better research.

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