Work in Progress: Ways of Thinking of Interdisciplinary Collaborators

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Abstract

Numerous calls by prominent organizations have been made to transform engineering education related research by adopting new ways of thinking. Environmental and Sustainability Education Research (ESER) offers a framework, Sustainability Education Framework for Teachers (SEFT). The SEFT offers a networked approach for considering complex problems and solutions through four ways of thinking including futures, values, systems, and strategic thinking. This paper attempts to leverage the work done within ESER by adapting the SEFT for engineering education research (EER) in the context of interdisciplinary collaborations between engineering and education faculty. Three engineering-education collaborators were interviewed in dyads to understand conceptualizations of futures, values, systems, and strategic thinking in relation to their joint research project(s). All three dyads provided specific examples of different ways of thinking from their shared research efforts. Preliminary findings suggest that a ‘ways of thinking’ framework could provide a useful guideline for engineering and education faculty planning to collaborate for interdisciplinary research as well as the overall EER community.

Overview

The world today faces complex problems ranging from climate change to health issues. Numerous calls by prominent organizations have been made in light of these global, sociotechnical problems to transform engineering education and related research by adopting new ways of thinking (ASEE, 2014; NAE, 2004; UNESCO, 2012). The Engineering Education Research (EER) Colloquies (JEE, 2006) specifically called for “research that will help characterize the nature of engineering knowledge (i.e., its technical, social, and ethical aspects) and ways of engineering thinking that are essential for identifying and solving technical problems within dynamic and multidisciplinary environments” (p. 260). The ways of engineering thinking need to be reconsidered to not only meet changing workforce demands, but also to increase awareness of the social impacts of engineered solutions, to promote diversity and inclusion in the profession, and to solve chronic issues of student retention or traditional lecture-based pedagogy.

According to Harel and Sowder (2005), ways of thinking is an approach to solving complex problems through coherent patterns in reasoning. Ways of thinking is not a heuristic, but rather a systematic thought process that informs decision-making. We envision and utilize ways of thinking in this study as an approach with which engineering education researchers think, act, and engage with their research.

EER is an emerging and naturally interdisciplinary field that has drawn on lessons learned from other fields, including education, psychology, and the learning sciences (Borrego & Newswander, 2008; Fortenberry, 2014). A similarly emerging field, Environmental and Sustainability Education Research (ESER), offers yet another field for EER to garner insights. EER and ESER share a common initiative of solving practical problems in their disciplines. ESER has focused on addressing large societal and environmental problems through education,
while EER has concentrated on engineering education practices and its alignment with the changing needs of society. There is without a doubt room for each field to gain insights and learn methodological approaches from one another given their inherent interdisciplinary natures and common underlying purposes (Lönngren & Svanström, 2015).

ESER offers a framework called the Sustainability Education Framework for Teachers (SEFT) that conceptualizes different ways of thinking and teaching of sustainability (Warren, Archambault, & Foley, 2014). SEFT aims to build sustainability literacy through four ways of thinking - futures, values, systems, and strategic thinking as shown in Figure 1 (Warren et al., 2014).

![Figure 1. Different ways of thinking conceptualized under the SEFT](image)

Futures thinking involves exploring the present with anticipatory approaches to understand and prepare for future changes, problems, and solutions. Values thinking concerns the integration of justice, equity, and ethics in designing a solution. Systems thinking is about considering holistic approaches to problem-solving that understand and analyze the complexity of various elements and their interrelationships in the overall ecosystem. Strategic thinking involves the ability to collectively develop a plan, design potential interventions, and consider possible alternatives that could lead to innovation in addressing today’s challenges (Warren, et al., 2014).

This paper is a first step toward adapting the SEFT for EER by qualitatively examining the use of these four ways of thinking in the context of interdisciplinary collaborations between and among engineering and education faculty. These types of collaborations are important to assess because many National Science Foundation (NSF) proposals require a partnership between an engineer and a social scientist (Wankat, Felder, Smith, & Oreovicz, 2002). The underlying notion behind these forced collaborations is to change existing engineering education practices and bring in innovation. This begs the question of whether or not such collaborations bring about change and what influences change from happening. Our research questions investigate the impact of ways of thinking on these collaborations and ask:
RQ 1: What ways of thinking within engineering and education faculty collaborations bring about change?

RQ 2: How do these ways of thinking manifest in the collaborators’ research?

RQ 3: Are there model uses of ways of thinking to instantiate productive collaboration between engineering and education?

This Work in Progress attempts to provide a descriptive study that lays the foundation to answer these questions by understanding what emerges in the specific ways of thinking of engineering-education collaborators.

**Research Methods**

**Participants**

Three engineer-educator dyads were purposefully selected using maximum variation sampling (Creswell, 2014). Maximum variation sampling considered the context of the collaboration (undergraduate engineering education, K-12 setting, or education in engineering research centers) as well as team members’ experience with interdisciplinary collaborations. The following subsections provide details of members’ background and their collaborative research.

**Team A: Kyle and Betty.** Kyle is a Professor of Engineering and Betty is a Professor Emerita within Education. Kyle and Betty worked together for 13 years on four funded projects that has resulted in six journal articles and 44 conference publications. Their research has examined improving classroom teaching through the use of real world examples, frequent formative feedback, professional development of K-12 teachers, and a variety of technological tools. The results of their work have innovated the education of engineering at all levels to provide a more active and engaging experience for students.

**Team B: Henry and Janelle.** Henry and Janelle work together within an NSF Engineering Research Center. Henry is an Assistant Professor of Engineering. He has worked with the center for five years; where Janelle is the Education Director. She also has an Associate Professor appointment within the College of Education. The research focus of the center is to advance photovoltaic science, technology, and education to sustainably transform electricity generation for the growing demands of energy across the world. Henry and Janelle have directly collaborated through the center via a summer research program that provides undergraduate students research experience relevant to industry. They have also written and been awarded a separate grant to further support the program. This was Henry’s first interdisciplinary research experience and the first interdisciplinary research experience with engineers for Janelle.

**Team C: Kelly and Wendy.** Kelly and Wendy have been close friends since their graduate school days and were fortunate to both obtain faculty positions at the same institution. Kelly is an Assistant Professor of Engineering and Wendy is an Assistant Professor of Learning Sciences. Their first research collaboration together involved design of a high school science textbook that was informed by learning sciences theories and served as a collaborative resource for knowledge curation and student community building. The project included user centered design activities to
understand current textbook usage practices of students and teachers along with participatory design workshops to discern student vision of a future textbook. Kelly and Wendy together have one journal article and five conference publications connected to this project.

**Data Collection**

The primary source of data were interviews conducted in dyads with collaborating engineering and education faculty members. Semi-structured interviews lasting approximately 60 to 90 minutes were designed and implemented to elicit understandings about futures, values, systems, and strategic thinking and how these ways of thinking were used by the engineer-educator teams. Dyads were first asked to describe their collaborative projects followed by a moment to reflect individually. The individual reflection involved writing about their thinking related to their engineering-education collaboration. This activity was used to prepare participants for verbalization of their thoughts during the dyad interview. Four primary questions were used for each interview. Additional questions were included based on participants’ responses.

1. Futures thinking: Please describe how you considered plausible scenarios of outcome for your collaborative work and its effects on the future changes and solutions for EER.
2. Values thinking: Please describe how societal values or norms of equity, inclusion, and social justice played a part in your work.
3. Systems thinking: Please describe the ways in which you thought about the various components of your project and their part in the bigger context of the engineering education system.
4. Strategic thinking: How did strategic thinking play a part in your work or in deciding on a course of action for the project?

**Data Analysis**

Qualitative data analysis was informed by the SEFT framework and followed an inductive approach outlined by Miles, Huberman, and Saldàña (2014). The lead researcher identified the essential idea(s) found in each participant’s response and labeled these with descriptive codes. The coding scheme was reviewed by another member of the team and revised as needed. The lead researcher then looked for repeated instances of these codes across all participants’ data. Finally, codes were merged to yield major themes of interest. These codes pertained to meaning, process, and specific examples of particular ways of thinking of engineer-educator collaborators. The data was additionally analyzed for two additional insights: 1) grouping statements by code to uncover themes within and across participants, and 2) looking for and understanding counter-examples of thinking, i.e., statements where participants talked about barriers that prevented them from engaging in a particular ways of thinking.

**Research Insights**

Each team provided specific examples of futures, values, systems, and strategic thinking from their research and discussed what these specific ways of thinking meant to them. The following subsections synthesize the findings for each way of thinking.
Futures Thinking

All three teams readily agreed and remarked repeatedly that the problem they were trying to address through education was future workforce and/or future citizens. For example, Henry said, “the research we do has to be cutting edge enough for students to change people’s lives as future energy citizens.” Teams B and C conveyed that they were “trying to advance state of the art” in education (Team B) and “develop educational models that could influence the larger community” (Team C). Team A mentioned that they “did not set out to worry about futures thinking”, but the proposals they wrote were “transportable” and “sustainable”. Team A’s proposed approaches with the strategies, assessments, and outcomes were not just limited to a particular situation (e.g. a department or a given population), but “represented a model that could be applied in many different settings and could be used by other institutions.” In addition, the work “would continue to be sustained into the future, even after the funding had expired.”

Overall, futures thinking to the participants meant continuous improvement, a sense of mission, potential broad impact of research, and sustained outcomes beyond funding. Futures thinking also represented facilitation of metacognition in student learning and faculty training to develop their futures thinking. Futures thinking was about imagining what might look different in engineering education and using that imagination to inform current designs and processes as well as capturing students’ imagination to change their career-paths and lives through education.

Values Thinking

Values thinking resonated with participants and seemed pertinent to their collaborative efforts, however, it was interpreted in multiple ways considering either diversity and inclusion or value creation. Team B engaged in values thinking trying to recruit a diverse cohort of participants. They realized that their larger team had “different ways of thinking about diversity, its importance, and what they're trying to do with it”. They “struggled to think about what diversity meant.” They also consciously thought about access as they wanted to recruit students who normally would not have access to research opportunities at their institutes. Values thinking from the perspective of diversity for Team C was a bit different in that it meant being “more inclusive in participant selection, trying to get diverse voices and representation in their research, bringing what the user cares about into the design, and really taking the user's culture into account.”

Values thinking was also discussed as a way of value creation, i.e. defining good research and contributions. Each discipline – engineering and education – define what is valuable to the discipline differently. This meant a priority was placed on “putting together a project where each of the discipline’s values were represented so that each contributing member got something out of it.” Values thinking was seen as contributions and generalizations in some cases, while others mentioned the ‘need approach benefits per cost and competition’ process.

The relevance of values thinking to these collaborations was not always inherent to the broader research group or engineering community. Some stated it to be “difficult to get [values thinking] to be a main thrust,” which forced them to “work around the edges.” Team A specifically mentioned two barriers to overcome within engineering contexts: 1) inherent biases, i.e., "people’s assumptions that they have no biases” and 2) one size fits all approaches. It was
challenging for Kyle and Betty to “create an awareness and a realization that when you engineer solutions, you're not dealing with a homogenous set of users.” They had to compromise at times because, “when you have all these people in the room and they're participating in a grant and you're not telling them this but what they're hearing is, everything they've ever done is wrong, that's what they're hearing.”

Overall, values thinking for the participating teams spanned a broad spectrum. These included design of gender-neutral experiences and exploration of inclusive practices in engineering classrooms, inclusion of diverse viewpoints, selection of diverse research subjects, and consideration of the value contribution of their research.

**Systems Thinking**

Systems thinking was identified as either a pervasive component of the collaborative work or completely absent. For Team A, systems thinking was used to link different parts of their proposal together. They considered a series of questions, like “what's being done, what isn't being done, what we want to do, how we assess it and what our measurable objectives are, [and] what our evaluation scheme is going to be, all of these things tied together as a system. When you change one part, you have to change another.” Team B similarly used systems thinking to “think about the linkages between the projects; how the students could speak to each other across their projects and how those projects together cohered into a set”, and how the projects could “affect the labs and the larger center community.” The linkages went beyond to “consider the interdependencies and interrelationships among the members of the diverse cohort, among the student participants and their mentors” and how they could use those relationships to “catalyze learning for all the members.”

Team B discussed a second example of systems thinking via the holistic consideration of products from their research. They tried to make sure that all elements of their product were working in a coherent whole. Henry elucidated, “For student capabilities, there’s a lot more than the ability to go in the lab and do experiments; [for example] how to be an audience member, how to be engaged, how to present, how to work in a team. Students as the product and what it means to be a holistic product, is part of our systems thinking and how we designed the program.”

Team C mentioned regrettablly that their project suffered from the lack of systems thinking. Kelly said, “where we really faltered was in systems thinking, because we never quite brought everything, all the different elements of the project together.” The three main components of the project “failed to inform and learn from each other’s findings for further research and development.”

Overall, Team A and B demonstrated great benefits in using systems thinking to make links across various components of their projects and to consider project products holistically. Team C did not demonstrate systems thinking, but recognized the lack of such thinking as a major deficiency in bringing together different elements of their project.
**Strategic Thinking**

Strategic thinking for all three teams involved considering the variety of solutions for a given problem, conceptualizing potential prototypes, and assessing the relative merit of the approach or a model. As Team A explained, strategic thinking was “using the scientific method in a different way, looking at creating different approaches to things that have been done before.” Teams A and C also talked about strategic thinking in terms of developing a plan of action to achieve the desired vision; which translated for Team C into “the role of the prototypes [and] iterating towards better solutions” and for Team A into “flexibility in solutions to cater to different segments.”

Teams A and B mentioned that strategic thinking was crucial to any research process and that’s what they were trying to give to their students, “the ability to think strategically the process of defining the problem or hypothesis, generating an experimental plan, executing that experiment and communicating the ideas with others” (Team B). It was evident that all three teams were thinking about strategies that support student learning and engagement “to teach better so [students] can think more analytically and strategically” (Team A).

Participants reported use of strategic thinking during typical grant and paper writing processes of planning, strategizing, coordinating, and responding to reviewer comments. Strategic thinking was utilized to discern logistics and to leverage the resources of time, talent, and budget effectively. Reflecting back, Kelly mentioned that “all the synthesis was sort of intellectual, but it wasn't actionable”. They could have used further strategic thinking in their project to build in the natural outflow and inflow of students graduating and joining, and to consider explicit channels of actionable communication throughout the whole project.

Finally, strategic thinking was also evident in the participants’ collaboration itself that sought complimentary and non-overlapping expertise and capabilities. As Betty explained, “there’s a real framing difference when you collaborate and the kinds of questions you ask are really, really different. The instruments you choose and the outcomes are really different.”

Overall, strategic thinking captured the focus of all teams’ work, connecting futures and systems thinking into feasible actions. It signified diversity of solutions, flexibility, finding opportunities for innovation, collective synthesis, and linking resources for optimum use.

**Future Work**

Additional interviews are currently underway and observational data will be gathered from participating teams’ project meetings to further examine how engineering-education collaborators see these different ways of thinking impacting their work. Other potentially applicable ways of thinking will be examined. We are also considering an open-ended survey with a bigger population of collaborators working on engineering education projects.

**Concluding Remarks**

The need for re-conceptualizing how we think about engineering education necessitates research that identifies ‘ways of thinking’ that consider future sociological and technological challenges
and enduring impact. The present Work in Progress study is the first foundational piece to understand what emerges in the ‘ways of thinking’ for engineering education researchers. We sought to gain this understanding based on four specific ways of thinking identified in SEFT, which include futures, values, systems, and strategic thinking.

Preliminary findings on futures thinking highlight the value of transportable and sustainable research. Values thinking was acknowledged by participants as relevant to the field, but diverged in meaning and adoption; indicating a need for additional research. Examples of systems thinking, or lack thereof, indicate the importance of linking all elements and scoping the problems and solutions in a larger context. Findings on strategic thinking describe participants’ considerations on diversity of solutions along with viability and efficiency of their interventions.

The outcomes of the larger future study have potential implications for engineering education teaching and research. Such a study builds on the existing body of knowledge regarding futures, values, systems, and strategic thinking; while initiating a first step toward an ‘EER ways of thinking’ model. We believe such a model transcends disciplinary boundaries to identify novel ways of thinking and factors that may contribute to the success of collaborative EER projects. Recommendations from this research could be especially helpful to engineering and education faculty members who are planning to collaborate. There is also a direct link of any EER to engineering classrooms. New skill-sets and related thinking abilities required from future engineers to solve sociotechnical and/or interdisciplinary problems pose a pedagogical challenge for engineering faculty. The outcomes could provide guidance for engineering faculty to prepare their students for the ways of thinking they will need to be successful in their future careers. We anticipate that a ‘ways of thinking’ model could serve as an organizing and motivating structure to frame decisions throughout all engineering education endeavors.

References


