STUDIES IN ENGINEERING EDUCATION

Dalal, M., et al. (2021). Developing a Ways of Thinking Framework for Engineering Education Research. *Studies in Engineering Education*, 1(2), pp. 108–125.

THEORY

Developing a Ways of Thinking Framework for Engineering Education Research

Medha Dalal, Adam Carberry and Leanna Archambault

Arizona State University, US

Corresponding author: Medha Dalal (medha.dalal@asu.edu)

Background: Numerous calls have urged researchers to adopt novel ways of thinking in order to address complex challenges within the engineering education system. The field lacks shared criteria and understanding to characterize ways of thinking, particularly in the context of engineering education research. Ways of thinking as a lens for considering and addressing complex challenges has the potential to bring about systemic change.

Purpose: This work aims to initiate a vision for a ways of thinking framework specific to engineering education research contexts. The purpose is to highlight how ways of thinking can be embedded in research practice as a means to enact systemic change.

Scope: Four specific ways of thinking – futures, values, systems, and strategic – are explored by reviewing literature from different fields and making connections to engineering education research. Each way of thinking is illustrated by application examples. A compilation of the underlying concepts, abilities, and enhancement approaches for each way of thinking is also presented.

Discussion/Conclusions: Ways of thinking is perceived as a concept in theory, but can and should be used in practice to innovate. Using futures, values, systems, and strategic thinking in an integrated manner can build capacity for researchers to push toward systemic change.

Keywords: ways of thinking; framework; systemic change; futures thinking; systems thinking; values thinking; strategic thinking

Introduction

Ways of thinking is a term that describes a particular mindset or thinking habits for an individual (Entwistle, 2009; Nakamura, 1991). Various ways of thinking can be used to generate creative solutions to complex problems of practice, influence culture, and push efforts toward systemic change (National Academy of Engineering, 2015; Schön, 1992). Attention to ways of thinking has increased in recent years as a means of discussing how to engage with a problem. The attention has led to numerous calls in engineering education urging researchers to adopt novel ways of thinking to address long-standing issues, including diversity, equity, inclusion, student recruitment, student retention, curricular change, and pedagogy (National Science Board, 2007; National Science Foundation, 2017; McKenna et al., 2014).

The focus on ways of thinking emerged in engineering education over a decade ago as part of a broader conception of engineering education research (EER) ("The Research Agenda for the New Discipline of Engineering Education," 2006). The National EER Colloquies aimed to create a coherent research agenda for the discipline of engineering education in light of the calls for more and better engineers. The steering committee for the colloquies identified five focal areas of EER: epistemologies, learning mechanisms, learning systems, diversity and inclusiveness, and assessment ("The Research Agenda for the New Discipline of Engineering Education," 2006). A ways of thinking lens that considers and addresses complex challenges across all five focal areas has the potential to help bring about systemic change in engineering education.

Funding agencies have embraced this idea and have encouraged collaborations across disciplines and institutes to galvanize different ways of thinking. Former National Science Foundation (NSF) program director, Dr. Elliot Douglas, extolled the importance of ways of thinking in EER:

> "You don't start from I want to do this activity," said Douglas. "You start from I want to make this cultural change. That's a very different way of thinking […]Let's think about how to not just cross-fertilize but cross-collaborate

> and create these larger partnerships that can work more broadly and at a larger scale to impact the engineering education field. What we want is broad, radical change in engineering education." (National Academy of Engineering, 2017, p. 8)

The demand for "an innovative and inclusive profession" (National Science Foundation, 2017, p. 3) and the general call to focus on ways of thinking has not yet led to a set of shared criteria or a common understanding to characterize EER ways of thinking. Ways of thinking continue to be taken for granted within the actual practices of research and teaching (Johansson-Sköldberg et al., 2013; Schön, 1992). Numerous indirect mentions can be found in the literature (Adams et al., 2011; Borrego & Newswander, 2008; Viefers et al., 2006). These references acknowledge differences in ways of thinking across disciplines or gender, but lack conceptual weight. It is not a wonder then that Case and Light (2011) called for "research studies that are able to go beneath the surface of common sense ways of thinking about engineering education" (p. 190). Such work to address and identify what constitutes *ways of thinking* for EER is still at a nascent stage.

The current research presents the first step in a ways of thinking framework development process that involves a series of activities, including a literature review, review of existing instruments, stakeholder analysis, and content experts' perspectives (Purzer & Cardella, n.d.). We draw on available literature to present the first step in developing a "Framework for Applying Ways of Thinking in Engineering Education Research" (FAWTEER). We argue that ways of thinking, while perceived as a concept in theory, can and should be used in practice as a structure for solution-oriented outlooks and innovation. This exploratory, yet critical look aims to achieve four goals: 1) show the relevance of ways of thinking perspectives to EER using a theoretical foundation; 2) highlight the ways in which ways of thinking can or should be embedded in EER to help bring about systemic change; 3) provide a concrete reflection point for researchers to consider how different ways of thinking drive their projects and affect processes and results; and 4) initiate a vision for a ways of thinking framework specific to EER.

The following sections operationalize ways of thinking and present a framework that conceptualizes four specific ways of thinking for addressing complex engineering education challenges. We contextualize each way of thinking for EER and discuss how a ways of thinking framework can and should be embedded into research practice. A few suggested approaches to enhance ways of thinking are discussed before sharing a critical reflection that considers broader implications for various stakeholders within the engineering education ecosystem as well as avenues for further exploration.

Ways of Thinking

Exploring ways of thinking first requires a foundational understanding of thinking. David Sousa (2016), in his book, *How the Brain Learns*, depicted thinking as:

> …easier to describe than to define. Its characteristics include the daily routine of reasoning – where one is at the moment, where one's destination is, and how to get there. It includes developing concepts, using words, solving problems, abstracting, intuiting, and anticipating the future (p. 246).

Sousa further noted that creativity, communication, logic, generalization, anticipation, intuiting, valuing, and conceiving are some of the different ways of thinking that ultimately manifest in our actions and behaviors. The present study is grounded in the notion that there are multiple ways of thinking. These ways of thinking facilitate different strategies for innovation and influence subsequent actions to address problems as often suggested under knowledge-to-action models (Best & Holmes, 2010).

Various fields of study have explored ways of thinking. Educational researchers have frequently attempted to describe numerous ways of thinking, including cultural, logical, pragmatic, mathematical, and language-oriented thinking (Harel, 2008; Merryman, 1986; Meyer & Land, 2003; Slobin, 1996). Business and finance research has portrayed ways of thinking as an intuition of pattern recognition combined with anti-intuitive rules that inform decisions and judgements (Douglas, 2000). Learning sciences considers ways of thinking as an approach to solving complex problems through coherent patterns in reasoning (Harel & Sowder, 2005). Environmental and Sustainability Education Research (ESER) uses ways of thinking as a lens for considering and addressing complex challenges regarding sustainability literacy (Warren et al., 2014).

These conceptualizations of ways of thinking were considered when operationalizing the framework for the EER contexts. We accept that ways of thinking are particularly relevant when considering complex problems as expounded upon in the definitions used in ESER and learning sciences (Harel, 2008; Warren et al., 2014). The definition by Douglas (2000) suggests that ways of thinking involves intuition (pattern recognition) as well as a systematic thought process (following rules). We believe that ways of thinking are rarely intuitive and include a systematic thought process that informs decision making. The definitions may vary among different fields, but there is agreement that ways of thinking are not a heuristic, but rather a set of principles for examining and considering problem-solution constellations in a coherent fashion to inform decision making.

We define ways of thinking for EER as an approach with which researchers intentionally think, act, and engage in their projects and make decisions. Ways of thinking represent a comprehensive approach for questioning, researching, evaluating, reflecting, and acting upon complex interdisciplinary problems with a solution-oriented outlook. In other words, ways of thinking guide and explain what engineering education researchers do, how they think, how they make decisions, and how they engage in research endeavors to bring about change in the existing system.

Ways of Thinking Framework

EER is an emerging and naturally interdisciplinary field that has drawn on lessons learned from other fields, including education, psychology, and learning sciences (Borrego & Newswander, 2008; Fortenberry, 2014). Another interdisciplinary field to draw additional lessons from is ESER. ESER is a vibrant, post-positivist field of study with paradigmatic diversity and a history dating back to the late 1970s (Ardoin et al., 2013; Hart & Nolan, 1999). ESER and EER are both inherently interdisciplinary and share a common underlying purpose of solving complex, practical problems through education. Sustainability-focused problems are complex in nature and often require involvement of different stakeholders with conflicting interests and values (Lönngren & Svanström, 2015). Recent research bridging ESER with EER has been shown to strengthen the discourse of problem-solving (Lönngren & Svanström, 2015; Tejedor et al., 2018).

There are two frameworks within ESER focused on ways of thinking: 1) Framework of Sustainability Research and Problem-Solving Competence (Wiek et al., 2011), and 2) Sustainability Education Framework for Teachers (SEFT) (Warren et al., 2014). The framework by Wiek et al. (2011) proposes five key competencies for students in sustainability programs: anticipatory, normative, systems thinking, interpersonal, and strategic. SEFT, developed by Warren et al. (2014), proposes four essential ways of thinking to solve complex issues: futures, values, systems, and strategic. The focus on competencies in Wiek et al.'s (2011) framework makes it most appropriate for teaching and learning evaluations, while SEFT is designed to help understand complex challenges by making connections between and among seemingly unrelated topics. SEFT's focus on ways of thinking presents a solution-oriented outlook that could support researchers in the challenging process of transforming the system, which led to the decision to use SEFT to inform FAWTEER.

The four ways of thinking presented in SEFT have a direct focus on decision making and problem solving. Futures thinking centers on many different possible future outcomes considering future changes, problems, and solutions. Values thinking focuses on the integration of justice, equity, and ethics in designing a solution. Systems thinking pays attention to the complexity of various elements and their interrelationships in the overall ecosystem. Strategic thinking concentrates on developing a plan of action to achieve the vision (Warren et al., 2014). The SEFT ultimately aims to create literacy about ways of thinking and prepare teachers "through a fundamental shift and transformation in the way they act, think, and engage with the world around them" (Warren et al., 2014, p.3). The framework "embodies the knowledge, skills, and attitudes necessary for problem solving" for all stakeholders, especially decision makers (Warren et al., 2014, p. 11).

The combined four ways of thinking present a networked approach for questioning, researching, and reflecting in complex, interdisciplinary, and interpersonal situations. We argue that these four ways of thinking, while originally conceived for sustainability education, apply to EER contexts when adapted for addressing complex educational challenges. The following sections provide an in depth exploration of each way of thinking drawing from the broader education, psychology, and business literature.

What is Futures Thinking?

Futures represent multiple possibilities of what could happen in time (e.g., 5, 10, or 20 years later), which makes futures thinking all about working to address tomorrow's problems today (Warren et al., 2014). The primary concern of futures thinking is learning from past decisions, understanding the present scenario, anticipating possible consequences of today's actions (or non-actions), and changing the nature of decision making in the present (Miller, 2003; Warren et al., 2014). Using futures thinking requires taking a functional view and preparing to alter trajectories as seen in the moves of grandmaster chess players or wildfire supervisors (Klein et al., 2011; McLennan et al., 2009). Futures thinking is sometimes confused with or equated to predicting or forecasting (Klein et al., 2011). Predicting is externally directed and concerned with guessing future states of the world, while futures thinking is a type of sense making to guide decisions. Forecasting is about guessing what the future will look like, while futures thinking imagines multiple futures and works toward a preferred future. Futures thinking is also sometimes mixed up with strategic thinking (see *What is Strategic Thinking?*), which involves developing a strategy or plan to achieve a particular vision. Futures thinking is about visioning itself and considering how to prepare the next generation to consider a multitude of possible futures (Warren et al., 2014).

What is Values Thinking?

Values are basic convictions about right or wrong, good or bad, and desirable or undesirable; which makes values thinking about ethical and normative focused thinking (Warren et al., 2014). Vesilind (1991) described values thinking as the recognition of how decisions are made, not which decisions are correct. The underlying notion is that values thinking is not so much about ethical theories or moral values, as it is about recognizing the concepts of ethics, equity, and social justice. Values thinking involves understanding these concepts in the context of varying cultures before making decisions (Vesilind, 1991; Warren et al., 2014). Stilgoe at al. (2013) further clarified values thinking as "holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge, and being mindful that a particular framing of an issue may not be universally held" (p. 4). Values thinking requires reflexivity to draw connections between external value systems and research practice to be able to provide values-based orientation to problem analysis, recognize cultural norms, and collaborate with stakeholders for critical consideration of positive and negative aspects of a solution from a variety of perspectives (Guston, 2013; Holifield et al., 2010; Vesilind, 1991; Veugelers, 2000).

What is Systems Thinking?

A system is a bounded entity of many elements or subsystems that function as a whole through the intricate web of interrelationships, which makes systems thinking a holistic approach to problem solving (Fordoyce, 1988). Systems thinking accounts for elements and interdependencies of subsystems while working within the whole (Godfrey et al., 2014; Kellam et al., 2008; Peters, 2014). Wiek et al. (2011) suggested that systems thinking does not equate to complete knowledge, but rather to an understanding of structures, functions, and causal loops that consider perceptions, intent, decisions, and constraints. Spector and Davidsen (1997) also explained that systems thinking is an understanding of the complexity and dynamics of a system, while recognizing the notions of delay, uncertainty, and nonlinearity. The sum of these ideas suggest that systems thinking entails: a) an awareness that every problem is situated in a bigger context; b) an ability to understand constraints and make connections; c) a realization of the consequences of an action due to cascading effects; and d) an acceptance that there might be elements invisible at any given moment, but that these elements govern the system nonetheless (Meadows, 2008; Senge & Sterman, 1992).

What is Strategic Thinking?

A strategy is a plan of action, which makes strategic thinking the ability to create a plan of action to achieve a desired vision (Warren et al., 2014). Strategic thinking is often perceived as a leadership skill (Bolman & Deal, 1991) involving the envisioning of goals and objectives, collectively developing a plan, and considering appropriate courses of action and resource allocation that could lead to innovation in addressing today's challenges (Wiek et al., 2011).

Strategic thinking, strategic planning, futures thinking, and critical thinking are terms that are often used interchangeably, but they do in fact hold different meanings. Lawrence (1999) clarified the difference between strategic thinking and strategic planning by describing strategic thinking as a creative, divergent process involving synthesis, while strategic planning is a conventional, convergent, and analytical process. Strategic planning is a process used "to operationalize the strategies developed through strategic thinking and to support the strategic thinking process" (p. 10). Bassett (2012) further clarified the difference between these two terms suggesting that strategic thinking should occur on a regular basis as part of daily activities, while strategic planning happens only periodically.

Strategic thinking is future oriented, but is not equivalent to futures thinking. These two ways of thinking are differentiated in that futures thinking imagines a preferred or likely future and works "backward to map out the sequence of decisions and actions necessary to reach the assumed future" (Darji & Jani, 2009, p. 47). Strategic thinking involves the specific actions and steps needed to achieve the envisioned future as well as the evaluation of novel strategies to respond promptly and effectively to unforeseen circumstances.

Strategic thinking and critical thinking are also often confused terms because strategic thinking uses critical thinking as a tool (Lawrence, 1999). Critical thinking involves the evaluation of the content on hand, whereas strategic thinking goes beyond and analyzes consequences, implications, and indirect effects due to interdependencies in the larger context to consider both short and long-term objectives. Consequently, strategic thinking is the process in which abilities comprising systems and futures thinking are translated into action for change, including the ability to enact specific steps and actions to get things done (Wiek et al., 2011).

An Integrated Approach to Implementing Ways of Thinking

Each way of thinking provides an organizational structure when considered individually, but in practice they naturally interconnect through mutual augmentation of one another. For example, futures thinking might consider projected numbers of societal demographics in conjunction with values thinking when envisioning long-term scenarios. It is helpful to consider the ways in which each way of thinking can be implemented separately or together to address complex issues before delving into how each way of thinking applies to EER.

An example where all four ways of thinking can and should be used together to address a complex problem is city planning. Futures thinking can be employed to envision how a particular city might plan for growth by considering current population trends and projecting the next 5, 10, or 15 years. Values thinking and systems thinking together can be implemented to consider how economic, societal, and environmental concerns might influence various subsystems as well as the wants/needs of various stakeholders (e.g., residents, business owners, policy makers, industry professionals, etc.). Strategic thinking can be applied in this scenario to devise a city plan that puts the goals of futures, values, and systems thinking into action. Strategic thinking can also be used as an evaluative tool to consider how enacted policies, plans, and processes are meeting or exceeding goals, such as those for strategic growth, water usage, or renewable energy production. Employing strategic thinking in this way can help inform whether or not policies are supporting future goals. Using the four ways of thinking in such a way can help avoid myriad problems in cases of unfettered city growth.

It is important to note that ways of thinking when used together can also create conflict under certain situations. For example, acting upon values thinking may not align strategically with the direction of the project. A networked approach of integrating the ways of thinking becomes crucial to avoid such conflict. Integration of all four ways of thinking creates a harmonious effort "rather than relying on piecemeal processes that highlight particular dimensions and not others" (Stilgoe et al., 2013, p. 7). This integration is where we see the four ways of thinking as lenses that provide the opportunity to extend and enhance any EER inquiry.

Framework for Applying Ways of Thinking in Engineering Education (FAWTEER)

A goal of this research is to take a step toward a framework that identifies concepts and concrete abilities or skills for each way of thinking within an EER context. **Table 1** demonstrates the first step toward that vision by capturing the underlying concepts, abilities, and approaches to enhance the four ways of thinking for EER. Abilities represent the capacity researchers can build or use while engaging with the four ways of thinking. Associated skills and abilities can be developed or applied as part of implementing each way of thinking.

Table 1: Compilation of concepts, abilities, and developmental approaches for the four ways of thinking within FAWTEER.

Thinking	Concepts	Abilities developed as part of each way of thinking	Enhancement approaches
Futures thinking	• Time including: a) short and long term, b) past, present, and future temporal phases, c) states, and d) continuity • Uncertainty • Disruption • Probability • Plausibility • Desirability	• Recognizing the rapid pace of change in the world (Burt & van der Heijden, 2003) • Pro-actively hypothesizing 'what if' scenarios and contrasting them with present status (Inayatullah, 2008, Radcliffe, 2005; Robinson et al., 2011) • Shifting mental models and frames to different temporal times (Klein et al., 2011) • Identifying emerging issues, possible outcomes, potential threats, and exciting opportunities (National Academy of Sciences, 2007) • Connecting a "collection of methods, theories, and findings" to recognize trends and their potential future trajectories (Miller, 2003, p. 7; Robinson et al., 2013) • Re-scoping problem spaces by projecting an idea or design into the future (Lande & Leifer, 2009) • Anticipating positive and negative consequences of an idea (Radcliffe, 2005) • Anticipating the potential future consequences of inaction during present times (Wiek et al., 2011) • Considering disruption of existing patterns (Borrego & Henderson, 2014) • Handling uncertainty and ambiguity in the contextual environment (Burt & van der Heijden, 2003) • Acknowledging that multiple futures exist depending on our actions (Warren et al., 2014)	• Scenario building • Participatory workshops focused on anticipatory approaches • Delphi studies focused on envisioning engineering education • Trend analysis using statistical and simulation models
Values thinking	• Justice • Fairness • Reflexivity • Responsibility • Inclusion • Ethics	• Assessing a problem and its context comprehensively within and across cultures (Warren et al., 2014) • Discussing how decisions can be made, not which decisions are the correct ones (Vesilind, 1991) • Collaborating with stakeholders when designing a solution to consider positive and negative aspects of the solution from a variety of perspectives (Veugelers, 2000) • Recognizing cultural norms, including conscious and unconscious statements of values (Vesilind, 1991) • Recognizing micro-inequities in the system that contribute to the "non-inclusive" groups' experience (McKenna et al., 2018)	• Value-oriented assessment methods • Life-cycle analysis used in sustainability research • Immersing in the community of practice to strengthen inclusive approaches • Participatory approaches of consensus building

(Contd.)

Thinking	Concepts	Abilities developed as part of each way of thinking	Enhancement approaches
		· Understanding how integrating equity and justice impact solving problems (Holifield et al., 2010) · Drawing connections between external value systems and scientific practice (Stilgoe et al., 2013) · Identifying and considering the consequences, risks, and disadvantages of engineered solutions (Guston, 2013; Sarkikoski, 1988)	
Systems thinking	· Sub-systems · Non-linearity · Feedback loops · Constraints · Cascading effects · Multiple domains of society, including environment, economy, technology, etc.	· Assessing system complexity across different domains (e.g. society, environment, economy) and across different scales from local to global (Kellam et al, 2008; Wiek et al., 2011) · Considering cascading effects and feedback loops among system elements (Warren et al., 2014) · Seeing true causes of the problem that are further in time or space and may originate from different parts of the system (Nehdi & Rehan, 2007) · Uncovering different knowledge systems through which a problem in a particular territory can be perceived and then exploring different parameters and measurements that could be applied (Godfrey et al., 2014) · Conceptualizing a situation in a bigger context and articulating problems in new and different ways (Stroh, 2018) · Recognizing that there are no perfect solutions and that the choices made will have an impact on other parts of the system (Meadows, 2008)	· Social network analysis · Mapping out systems and subsystems, modeling different components, and denoting flows in particular directions · Causal chain analysis
Strategic thinking	· Action planning · Viability · Feasibility · Efficiency · Effectiveness · Intentionality · Alliances · Adaptation · Flexibility	· Developing a plan of action and framing decisions by how they contribute to achieving a particular vision (Warren et al., 2014) · Allocating resources of time, talent, and budget more effectively (Darji & Jani, 2009) · Identifying thrust areas for future research proposals (Halpin & Huang, 1995) · Working with the system and leveraging resources (Stollar et al., 2006) · Discerning real-world situations, including logistics, relationships, and changing political positions (Wiek et al., 2011) · Negotiating with all stakeholders to collaboratively achieve the vision (Wiek et al., 2011) · Continuously shaping and re-shaping the intent of a project and accordingly shifting directions (Halpin & Huang, 1995; Lawrence, 1999) · Adopting 'intelligent opportunism' to take advantage of the situation (Jasinski, 2004; Lawrence, 1999)	· Planning methodologies · Workshops focused on game theory, behavioral change, and decision support methodologies · Participatory approaches to collectively define criteria, critical success factors, and action items

The following subsections explain why futures, values, systems, and strategic thinking are important to examine within the context of EER. We outline a few specific actions that implement these ways of thinking along with suggested approaches. We also take an example of one EER project, Engineering for Us All (E4USA), and explain how futures, values, systems, and strategic thinking were applied to conceive and execute the project. The E4USA project (https://e4usa.umd.edu/) is a high school level engineering education initiative funded by the NSF. The initiative was launched in 2018 as a partnership among five universities across the nation to demystify engineering for high school students and teachers. Three key components of the project include the creation of: 1) a high school level engineering course(s); 2) an in-person and online teacher professional development; and 3) a sustained learning community of teachers, engineering educators, and practicing engineers that supports student pathways to higher education institutions. The project was conceptualized using futures thinking; recognizing the need for a greater number of engineering professionals in the country to meet future workforce demands. An expanded systems view led the project to focus on the K–12 subsystem. Values thinking suggested that the high school course should be all-inclusive, that is, open to all students and teachers from any type of background. Finally, strategic thinking was applied to write a grant proposal and create partnerships. We further describe each way of thinking as connected to E4USA in the following subsections.

Futures Thinking in EER

The engineering education system has traditionally focused on imparting technical skills aligned with the present day demands of industry and the needs of society (Grinter, 1955; Mann, 1918; Wickenden, 1930); however, there are a few conclusive examples of futures thinking in the evolution of the field. An analysis of trends by the Goals Committee (1968) resulted in a call to define the direction of the field 40 years ahead. The Engineer of 2020 report (National Academy of Engineering, 2004) suggested that approaches of the past, while successful in examining current needs of that time, were not enough to meet future needs that entailed changing demographics and complex interrelationships of disciplines. The report emphasized futures thinking as a way of expanding the appreciation of possible futures, visualizing probable futures, and creating bold new paradigms for preferred futures (National Academy of Engineering, 2004). The National Academy of Sciences observed a "recurring pattern of abundant short-term thinking" and urged researchers, policymakers, and funding agencies to engage in long-term aspirational thinking (National Academy of Sciences, 2007, p. 25). A committee commissioned by the NSF with the National Academy of Engineering and the National Academies of Sciences, Engineering, and Medicine examined the forces likely to shape engineering research, education, and innovations in the future over a 21-month study (National Academies of Sciences, Engineering, and Medicine, 2016). Their report, *A vision for the future of center-based multidisciplinary engineering research*, called for the need to distinguish design from problem-based learning, criticized the general model for doctoral education that has stayed the same for decades, suggested finding ways to better integrate undergraduate and graduate education, and recommended researching ways to teach entrepreneurship and creativity to students. The report also urged researchers to find new matrices to evaluate student performance on teamwork, leadership, creativity, global perspective, interdisciplinary thinking, and social responsibility.

Translation of these reports to EER suggests that futures thinking requires shifting mental models and frames to imagine new approaches of teaching by conceptualizing hypothetical futures, often as far out as 20 years (Klein et al., 2011; OECD, 2017). Researchers need to "think broadly, think big picture, and think way out of the box" to consider the changes that may occur in the field of engineering education in the next few decades (National Academies of Sciences, Engineering, and Medicine, 2016, p.4). Specifically, researchers need to develop models, processes, and practices, to adaptively prepare for future changes, problems, and solutions that will influence the larger engineering community (McKenna et al., 2014).

A futures-based approach requires repositioning research efforts to include thinking about what could happen, as opposed to what will happen. Researchers should envision where the engineering education system needs to go and how we might get there. Futures thinking requires the ability to recognize the rapid pace of change framed by the level of uncertainty and ambiguity within the contextual environment. Researchers need "to anticipate changing scenarios as stakeholder needs and system context change over time" and apply that knowledge when formulating decisions and considering consequences of future project ideas (Radcliffe, 2005; Rhodes & Ross, 2009, p. 46). Such ideas should consider advancing the state of the art in engineering education by answering the question, *where are we headed*? Researchers should connect diverse aspects of present-day engineering work to hypothesize factors that will be important to tomorrow's engineers. Emerging literature has suggested that researchers need to anticipate the skills that will be needed in the next century and accordingly propose teaching and learning models that provide opportunities for students to imagine a futuristic world with board social contexts (Gattie et al., 2011; Jamison & Mejlgaard, 2010; Lande & Leifer, 2009). For example, Lande and Leifer (2009) proposed a framework relating futures thinking (used as future thinking in the article), design thinking, engineering thinking, and production to teach engineering design. Their study analyzed students' design projects and concluded that forays into futures thinking allowed for resetting and re-scoping of the problems and bolstered innovation.

Futures thinking also entails understanding and accepting uncertainty (Warren et al., 2014). Engineers are traditionally trained to eliminate uncertainty (Lande & Leifer, 2009). Futures thinking suggests that the engineering education system needs to prepare the future workforce to handle ambiguity and make choices based on anticipatory changes (Borrego & Henderson, 2014; Huntzinger et al., 2007). Researchers should study techniques that strengthen future generation's technological knowledge, while preparing them to consider emergent outcomes within a complex societal system that cannot be fully known (Miller, 2003).

The example project, E4USA, was first conceived with futures thinking. Examination of current engineering enrollment numbers, degrees awarded, and projected future workforce demands suggested the need to increase the number of engineering professionals. A number of engineering college deans were contacted in future consideration of wide adoption across the nation, broad impact, and sustainability. The project was subsequently conceived as a national pilot for a high school engineering curricula.

Overall, futures thinking applied to the context of research includes: a) imagining disruption of existing patterns (Borrego & Henderson, 2014), b) conceptualizing research projects that are sustainable beyond the funding period (Dalal & Carberry, 2018), c) re-scoping of problem spaces that consider future scenarios (Lande & Leifer, 2009), d) embedding research projects within a larger constellation of goals considering infrastructure needs and long lasting impact in the future (Dalal & Carberry, 2018), and e) considering dissemination of research beyond academic readership for wider adoption of outcomes (Finelli et al., 2014; Jesiek et al., 2009). Futures thinking in EER is ultimately about "what engineering students should learn [...] to prepare for the future and how this might differ from what is taught today" (National Academy of Engineering, 2004, p. xiii).

Values Thinking in EER

Values thinking within EER translates into value-focused topics, including: a) diversity, inclusion, equity, and belonging (Lichtenstein et al., 2014; McKenna et al., 2018), b) social-humanistic approaches of teaching and research (Douglas et al., 2010; Guston, 2013; Sarkikoski, 1988), and c) ethical engineering practices (Barry & Herkert, 2014). These topics align with the National EER Colloquies' call for an engineering education system that reflects the society and provides social and ethical knowledge in addition to technical skills ("The Research Agenda for the New Discipline of Engineering Education," 2006). Answering this call means addressing the need for diversity and inclusiveness in the profession, recognizing diverse viewpoints, and creating fair engineered solutions through values thinking.

The first topic associated with values thinking entails challenging the status quo regarding diversity and equity, while creating a culture of inclusion and belonging. Addressing the historical bias regarding diversity and inclusion is a complex issue that involves understanding how politics, culture, and other social issues are inherent in the practice of engineering (Leydens & Lucena, 2017); and examining implicit biases and stereotypes on a continuum spanning individual perspectives, departmental and institutional values, as well as the values of the field. Prior research has hinted at the need to define the values of the field (Jesiek et al., 2009). A goal for engineering education should be to mirror the demographics of society (Mills et al., 2011; Swan et al., 2014), but several well-known issues persist regarding gender gaps, low enrollments of underrepresented minorities, and an overall chilly climate toward non-dominant groups (McKenna et al., 2018; Riley et al., 2014). The finer grained outcome of viewing values thinking in such a way can translate into specific actions for researchers, including developing inclusive pedagogies, championing system-wide diversity and inclusion efforts, and designing community engagement opportunities and outreach activities that consider underserved populations (Abaid et al., 2013; Lumsdaine & Lumsdaine, 1995; Swan et al., 2014). As an example, Abaid et al. (2013) conducted a K–12 engineering and robotics outreach program targeting public schools with underserved populations in engineering education. The results indicated an influence on students' perceptions of engineering as a more accessible discipline after participating in the program.

Values thinking also entails recognition of the social-humanistic side of engineering education. This means values thinking necessitates recognition of diverse perspectives, and consideration of contextual and individual experiences in research methodologies (Douglas et al., 2010; Riley et al., 2014). Douglas et al. (2010) explored challenges and promises of epistemological diversity reviewing literature from the broader social sciences as well as qualitative empirical studies from engineering education. The authors identified a number of challenges regarding assumptions about knowledge in the historically positivist field of engineering education. They urged researchers to embrace epistemological diversity (including within qualitative research paradigms) as it enables researchers to explore different questions and answers from newly created positions (Douglas et al., 2010). Riley et al. (2014) also argued for a move beyond "positivist ways of knowing" toward "inclusive and reflexive inquiry" that would consider context and experiences (p. 339).

Finally, values thinking is also about ethically grounded engineers who see themselves as global citizens and "understand how to adapt solutions in an ethical way" (National Academy of Engineering, 2004, p. 21). Sarkikoski (1988) wrote, "Social development has become the problem of technological thinking and engineering education" (p. 342). He concluded that technical and social problems, though seemingly different in nature, demand a coherent solution with direct connection to values thinking. Veugelers (2000) also stated, "Developing skills to analyze values and to communicate them is necessary to show students that values are constructs and that people can make choices for certain values" (p. 9). Consequently, values thinking also includes designing studies that teach future engineers to make choices that are fair, transparent, and equitable (Guston, 2013).

Engineering education has traditionally separated technical engineering content from the social, economic, and environmental impacts of engineering decisions. The discourse on ethics has expanded recently beyond issues of codes, compliance, and workplace ethical dilemmas to include the broader context of responsible engineering practice that considers intentions, actions, and unintended consequences of designed solutions (Barry & Herkert, 2014; Stilgoe et al., 2013). Stilgoe et al.'s (2013) proposed framework for responsible innovation uses an engineering case study to explore four dimensions of responsible innovation: anticipation, reflexivity, inclusion, and responsiveness. Stakeholders are challenged to use the framework to go beyond compliance and reflect on previously unexplored impacts, applications, and issues. Such examples necessitate new empirical studies focused on dispositions, decision processes, and systems (e.g., social, economic, and environmental) considerations. Research is needed, not only to understand engineering ethics in the workplace but also to create associations between moral values and technical subjects in the curricula (McCuen, 1990; Vesilind, 1991). Examples include integrating the topic of public health into civil and environmental engineering courses that discuss waste management systems or including historical preservation aspects into simulations and software designs for land development.

Values thinking applied in the context of the selected example project, E4USA, led to the design of the high school course to be all-inclusive in an effort to address issues of diversity and the lack of secondary-level engineering educators. The teacher professional development was designed to focus on engineering content as well as stereotype threats, implicit bias, and inclusive pedagogy. The curriculum included multiple lessons intentionally designed to prompt students to think about the issues of ethics, equity, and access as they learned about the Grand Challenges of Engineering and the United Nations Sustainable Development Goals. Attention was given to create a heterogeneous pool of high school partners where student access to engineering experiences may be limited by socioeconomic and cultural barriers. The project team considered diversity of location (e.g., rural, urban, etc.), student demographics (e.g., mixed gender, all-girls, etc.), and school affiliation (e.g., public, parochial, etc.) to select partner high schools.

Overall, values thinking applied to the context of EER does not mean that everyone needs to focus research efforts on diversity, equity, inclusion, or ethics. Values thinking applied to a research context includes: a) engaging the research team in thinking about diversity, what diversity means, importance of diversity, and ways of achieving diversity (Riley et al., 2014), b) considering distinct voices and representation among research participants with diversity of class, nationality, ethnicity, LGBTQ status, gender, disability, or age (Dalal & Carberry, 2018), c) understanding the difference between diversity and inclusion (Morley, 2018), d) embracing epistemological diversity (Douglas et al., 2010), and e) implementing reflexive research practices that are also transparent (Guston, 2013). Values thinking is ultimately one of the crucial components in bringing about deliberate change by understanding culture through interactions with all stakeholders, challenging the traditional epistemic assumptions, and constructing new directions toward helping humanity and life through engineering products and solutions (Douglas, et al., 2010; National Science Board, 2007; Riley et al., 2014).

Systems Thinking in EER

The system of engineering education from its inception has been grappling with multiple chronic issues of student retention, diversity, inclusion, overloaded curricula, and traditional lecture-based pedagogy (Carberry & Ohland, 2012; Goals Committee, 1968; National Academy of Engineering, 2004). McKenna et al. (2014) called for systems thinking to address these chronic problems. Systems thinking allows for a "30,000 feet" perspective, broadens the problem space, facilitates the asking of new questions, and expands the choices for possible solutions (McKenna et al., 2014; Wiek et al., 2011). Its nonlinear nature allows systems thinking to be quite complex, but capable of bringing about change that leverages interdependencies between sub-systems and cascading effects (Warren et al., 2014). Of particular interest to researchers would be the feedback loops from the peripheral elements (e.g., K–14 systems, university policies, international partnerships, accreditation bodies, and funding agencies) that can influence significant change within the system itself. McKenna et al. (2014) suggested that satisfying solutions will not be realized until understanding of the engineering education system goes beyond the institution, administrators, students, faculty, and curricula to include the sub-systems of accreditation boards, industry, federal agencies, professional bodies, primary and secondary education, and the global economy. Spector and Davidsen (1997) wrote, "It is often people's perceptions and goals that give rise to dynamic behavior" of the system (p. 129). Researchers should apply systems thinking to understand the roles and actions of stakeholders and how they are shaped by, and in turn, shape the dynamic system. Such approaches provide for a better grasp of the larger picture, highlight the importance of feedback loops within subsystems, and influence the broader ecology.

Researchers make connections when conducting research and interpreting data, but those connections often rely on hidden assumptions and implicit models. Use of systems thinking demands intentionality, clearly laid out assumptions, and sometimes explicit models with data evidence (Peters, 2014). Researchers should use a number of data-driven tools, including causal loop diagrams, network mapping, social network analyses, and process mapping to model dynamics of the engineering education system and subsystems (Madhavan & Lindsay, 2014; Nehdi & Rehan, 2007; Peters, 2014). Engaging in interdisciplinary projects also has the potential to provide insight into how others may see the engineering education system differently (Fordyce, 1988). Such approaches could make our assumptions explicit, help identify where to collect more data, raise new questions, and test hypotheses with calibrated data.

Systems thinking also ties in with the preparation of the future workforce. A recent report suggested that the next generation of engineers will be challenged to find solutions to problems situated within social and economic systems, such as water, energy, transportation, healthcare, environment, and housing (National Academy of Engineering, 2012). These problems will require engineers to have a sophisticated understanding of systems, components, social environments, and stakeholder effects. Complex societal problems demand an understanding of perceptions, intent, decisions, and constraints as part of systems thinking (Kellam et al., 2008; Wiek et al., 2011). Kellam et al.'s (2008) examination of mechanical engineering programs in the United States (US) and Australia indicated that systems thinking was integrated throughout the curriculum in Australian universities, but it was received in piecemeal within the US-based programs, often focused on individual parts without consideration of the whole system. Such findings put the onus on researchers and educators to integrate systems thinking across the full curricula and design experiential learning activities that encourage thinking with respect to loops, layers, and processes (Godfrey et al., 2014). Engineering faculty and researchers need to identify opportunities to expand their knowledge base on systems approaches and how these approaches could be broadly adopted for systemic change.

Systems thinking applied in the context of the selected example project, E4USA, considered the whole education system. The project addressed student retention at the undergraduate level by targeting feeder elements earlier in student pathways. Expanding the systems view led the project to focus on the secondary subsystem as opposed to undergraduate programs, which resulted in the design of a high school level engineering curriculum that aimed to increase students' self-efficacy toward engineering pathways. Systems thinking further suggested involving additional influential stakeholders (e.g., school counselors) into the learning community. An abridged version of the engineering professional development was offered to counselors and student success specialists to magnify the impact of the project.

Overall, systems thinking applied to the context of research includes: a) looking beyond the immediate effects and thinking about different domains (e.g., primary and secondary school, international, economic, and societal) and scales (e.g., local to global) when interpreting research results and considering implications (Kellam et al., 2008; Wiek et al., 2011), b) frequently synthesizing progress at various steps of a project to make connections between various research strands, goals, inputs, activities, participants, and outcomes (Dalal & Carberry, 2019), c) engaging the research team in thinking about what it means to have a holistic product or outcome (Dalal & Carberry, 2018), d) considering multiplicity of pathways in the system to achieve the desired outcome (Godfrey et al., 2014), and e) asking new questions by broadening the problem-space (Stroh, 2018). Systems thinking suggests that only by understanding the whole system structure will we be able to progress toward more satisfying, long-term solutions to the chronic complex problems plaguing the engineering ecosystem and society (McKenna et al., 2014).

Strategic Thinking in EER

A wealth of literature has examined critical thinking in the context of engineering education (Ahern et al., 2012; Woods et al., 2000), but little has been done to examine strategic thinking among researchers. Creative problem-solving strategies conceived as part of strategic thinking could help address complex engineering education problems (Lumsdaine & Lumsdaine, 1994). Strategic thinking enables researchers to recognize systemic inertia and barriers, create alliances, and work toward "viability, feasibility, efficiency, and efficacy" of interventions (Wiek et al., 2011, p. 7). The report *Infusing Real World Experiences into Engineering Education* indicated the need for strategic thinking to note potential disruptive advances in the field (National Academy of Engineering, 2012). Others have recommended strategic thinking to create interdisciplinary partnerships, identify the most important problems in the field, embrace flexibility in approaches and solutions, effectively manage resources, communicate with various stakeholders, and consider novel ways of applying research beyond academic readership (Borrego & Newswander, 2008; Dalal & Carberry, 2019; Jesiek, et al., 2010; National Academy of Engineering, 2008).

The converging forces of globalization, technology, and economic restructuring also make strategic thinking an essential skill for the future engineering workforce (Liao, et al., 2006). De Graaff and Ravesteijn (2001) explored what a complete engineer will require in the 21st century to work for a multinational company. Strategic thinking emerged as a required skill along with a shift in mindset from a *doer* to a *thinker* mode. The demands for these thinking skills have consequences for EER. Researchers need to design interactive simulations or interventions incorporating real-world projects to develop strategic thinking on the part of students (Davidovitch et al., 2006; Garcia-Perez & Ayres; 2012). Garcia-Perez and Ayres (2012) specifically suggested developing new models of active learning with an orientation toward practice. The authors indicated that strategic thinking could be developed through workshops with experienced researchers and engineers that discuss work strategies followed by reflection activities.

Strategic thinking applied in the context of the selected example project, E4USA, involved writing a grant proposal with buy-in from a number of deans of engineering colleges. Strategic thinking was also implemented to develop execution plans that covered partnerships with local high schools, credit and placement options for students, and collaborations with other existing programs and projects in secondary education to leverage system resources. A workshop was held at the end of the first year by the project team to engage in strategic thinking and identify critical success factors for scaling up the project.

Overall, strategic thinking applied to the context of research includes: a) establishing collaborative, strategic partnerships with researchers from other fields (Borrego & Newswander, 2008), b) creating mutually beneficial, strategic partnerships with stakeholders (Wiek et al., 2011), c) identifying the key thrust areas within the bigger project (Dalal & Carberry, 2018), d) strategically allocating limited resources of time, talent, equipment, information, and money (Darji & Jani, 2009), and e) working with the research team toward frequent and actionable communication (Dalal et al., 2017). As *The Engineer of 2020* report explained, "…using new strategic planning tools, we should reconstitute engineering curricula and related educational programs to prepare today's engineers for the careers of the future" (National Academy of Engineering, 2004, p. 51).

Implementation of FAWTEER

FAWTEER offers four ways of thinking to organize principles for questioning, researching, and reflecting in interpersonal, interdisciplinary situations. Implementation is not meant to be prescriptive as each way of thinking can be implemented in parallel or in isolation depending on the situation. However, using these ways of thinking in an integrated manner provides an opportunity to strengthen any EER inquiry as demonstrated in the example of the E4USA project. We see futures, values, systems, and strategic ways of thinking as four main compartments of a researcher's toolkit to critically engage with the surrounding world. The four ways of thinking can be used in any order but when applied in a combined fashion, they offer key insights into knowledge, skills, and abilities necessary for problem solving complex challenges in the field. Such a networked approach builds capacity for researchers and practitioners alike to be able to understand the broad and complex nature of engineering education challenges, conceptualize solution driven studies, and recognize the connections between research and practice, which could lead to greater systemic change. A few developmental approaches to enhance ways of thinking among EER researchers are suggested in the following section.

Enhancing Ways of Thinking

Ways of thinking are often taken for granted or partly ignored despite their influence on innovation (Johansson-Sköldberg et al., 2013). Researchers might be using one or more way of thinking, but unknowingly or in an implicit manner. The current study argues for the need to make these ways of thinking explicit throughout conscious research activities in order to challenge perceptions, designs, models, and processes that could lead toward systemic change. We recognize that systematic thought processes are rarely intuitive. Prior research has identified individual and team-level barriers that can interfere with ways of thinking, including fixation, pattern entertainment, disconnects between the data collector and the data integrator, team coordination, departmental silos, organizational policies, and automation (Boden & Borrego, 2011; Dalal & Carberry, 2018; Godfrey and Parker, 2010; Klein et al., 2007). This body of research suggests that explicit efforts are needed to improve ways of thinking and enhance the capacity of researchers and organizations.

Recommendations for futures thinking include using team-based scenario building approaches to strengthen temporal thinking that considers how systems and their operational environment may evolve over time (Rhodes & Ross, 2009), mental models to strengthen the use of high abstraction languages or metaphors (Klein et al., 2007), and participatory approaches of Delphi studies or workshops to build anticipatory competencies (Wiek et al., 2016).

Enhancement approaches for values thinking may require frequent and more explicit efforts because values are held convictions that may be subconscious and based on personal beliefs and/or misconceptions that may be difficult to change. Participatory approaches that focus on multi-criteria assessments, sharing stories of inclusive and non-inclusive experiences, case study analyses examining scientific practices, engineering ethics, and technology policy are some of the ways to enhance values thinking (Guston, 2013; Heikkerö, 2008; McKenna et al., 2018; Wiek et al., 2016).

Cultivating systems thinking for EER requires participatory modeling of the system itself (Gattie et al., 2011). Such approaches may include modeling and mapping using social network analysis, causal loop diagrams, iceberg models, and behavior over time graphs that highlight interconnections, causality, and invisible elements. Analytical thinking is inherent in all research, but professional development that emphasizes skills of synthesis could also lead to enhanced systems thinking (Ackoff, 1981; Kay & Foster, 1999).

Strategic thinking has been demonstrated through analyses of game theory problems (Benito-Ostolaza & Sanchis-Llopis, 2014). Workshops wherein participants navigate through game theory-based problem scenarios could foster strategic thinking about collaborative approaches of problem solving and enhance optimal decision making among partners. Heracleous (1998) advised using structured tools of planning and management to aid creative thinking and improve strategic thinking. Other avenues include participatory approaches and workshops focused on methods used in business and management, such as explicit criteria definitions, identification of critical success factors, and behavioral change management techniques (Bourne et al., 2000; Marsick & Gephart, 2003).

A breadth of additional literature on interdisciplinary collaborations further expounds upon improvement in ways of thinking. The literature has concluded that when professionals from different disciplines work together toward a common goal, they often deconstruct disciplinary ways of thinking, change their beliefs, values, and attitudes, and "assimilate new ways of thinking into new approaches to practice" (Frodeman, 2017; McCallin, 2004, p. 38). Kelly (2010) advises individual researchers to simply consider changes to current ways of practicing as a first step toward novel ways of thinking.

Discussion

The primary intent of this research was to take a step toward a ways of thinking framework specific to EER (**Table 1**). A framework is the "exposition of a set of assumptions, concepts, values, and practices that constitutes a way of understanding the research within a body of knowledge" (Schwarz et al., 2007, p. 41). EER is a growing field of scientific practice that does not yet have many frameworks specifically developed for its purpose (Borrego & Newswander, 2008; Fortenberry, 2014). We hope that the present research will serve as a stimulus to a larger community discussion about how futures, values, systems, and strategic thinking might be applicable to systemic change or how FAWTEER might be used by the community.

We foresee FAWTEER and the embedded ways of thinking – futures, values, systems, and strategic – as being four essential compartments of a researcher's toolkit. The integration of the four ways of thinking build capacity for researchers to situate their proposals and projects in consideration to the long-term impact, value orientation, and complex, intertwined nature of the broad system. The four ways of thinking become especially suitable for collaborative research where meaning making takes precedence as researchers share their domain-specific expertise, interpret multiple perspectives and decide on strategies to address issues at hand, and achieve their research goals (McKenna et al., 2009). The framework could be broadly applicable to several stakeholders in engineering education: researchers (from within and outside the discipline), educators, administrators, and policymakers. We also see FAWTEER being especially valuable to doctoral students and early career faculty as they learn to approach engineering education problems.

Equipping the engineering education system for 21st-century challenges is of paramount importance, not only in the US, but across the world (American Society for Engineering Education, 2014; National Academy of Engineering, 2004; UNESCO, 2012). The system needs a fundamental shift and transformation through pertinent research and innovative practices (Jamieson & Lohmann, 2012; National Academy of Engineering, 2017). The application of futures, values, systems, and strategic thinking together has the potential to be an important tool for researchers. The combined ways of thinking will allow researchers to be able to conceptualize and address a particular situation through a problem-solution pattern that may exist at a variety of temporal and spatial scales in the engineering education system.

We recognize that there could be other ways of thinking beyond those that we described that may apply to the context of EER (e.g., entrepreneurial thinking, computational thinking, or design thinking). We also acknowledge that the concepts, abilities, and suggested enhancement approaches included in **Table 1** are not necessarily an exhaustive list. The aim of this work is to provide a concrete reflection point for readers to consider how different ways of thinking drive their projects, affect the process and results, and impact planning and execution. We hope this research will inspire broader investigation of ways of thinking in different contexts.

Future Work and Implications

The present work is the first step toward a larger overarching goal of establishing a ways of thinking framework for EER. We have used FAWTEER to examine conceptualizations of futures, values, systems, and strategic thinking among nine collaborative EER projects at one institution. A survey was designed and implemented targeting specific NSF awardees to further explore the underlying dimensions of futures, values, systems, and strategic thinking (Dalal & Carberry, 2019).

Future research could pursue multiple different inquiries that together will lead toward characterization of various ways of thinking. This may include: a) gathering input on ways of thinking abilities from the community using the knowledge acquisition technique of card sorting (Spencer, 2009), b) conducting ethnographic studies to examine ways of thinking perspectives within diverse EER projects at multiple national and international institutions, c) pursuing Delphi studies to obtain a consensus of opinion on the concrete skills and knowledge for each way of thinking (Okoli & Pawlowski, 2004), and d) examining how policy changes might enhance ways of thinking that then inspire more creative, adaptive, and responsive research projects.

The current work highlights the usefulness of a conceptual ways of thinking framework that has a potential to push toward deep, systemic change. Funding agencies could devise grant solicitations that foster skills and abilities related to these ways of thinking and prompt their use in the field more broadly. Leading agencies and professional organizations such as the National Academy of Engineering or the American Society for Engineering Education could also design and promote workshops that engage researchers in such ways of thinking. As discussed, futures, values, systems, and strategic thinking are not heuristics; however, they do provide a structure for a solution-oriented outlook that can enable researchers to develop an expansive view of the problem at hand, consider how values play an important role, and build capacity to come up with solutions that consider long-term futures.

Closing Thoughts

The challenges faced by the engineering education system are multifaceted and need novel ways of thinking to address complex problems (Adams et al., 2011; National Academy of Engineering, 2015; National Science Foundation, 2017). Our work represents a unique attempt to explore futures, values, systems, and strategic thinking as an organizational structure to address engineering education challenges. We have made an argument that ways of thinking, often perceived as a theoretical concept, could and should be used in practice to innovate and inform research. The theoretical underpinnings contribute to the existing body of literature on futures, values, systems, and strategic thinking, while the integrated approach of implementation helps frame decisions regarding problem-solution patterns in all EER endeavors. We have articulated main concepts, concrete abilities, and potential ways of thinking enhancement approaches to initiate further development of FAWTEER. The framework seeks to build capacity for all stakeholders to explore how we can approach the field in new ways to address complex problems, teach using evidence-based approaches, bring about institutional change, and create a more innovative and inclusive profession.

Acknowledgements

The authors thank the reviewers, the associate editor, and the editors of the journal for their constructive comments and feedback.

Competing Interests

The following work was originally presented as part of the first author's dissertation in May 2019. The second author served on the first author's dissertation committee, while the third author served as her chair. This dissertation can be found using the following citation: Dalal, M. (2019). Interdisciplinary engineering research collaborations: Exploring ways of thinking using a mixed methods approach. Unpublished Dissertation. Arizona State University.

Future manuscript submissions are planned using this publication as the foundation for quantitative and qualitative studies of ways of thinking. This work was supported by the Arizona State University's dissertation grant under the Graduate Research Support Program. This work has not been associated with any receipt of external grants or funding, but does serve to benefit the authors as they seek funding to continue this work.

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How to cite this article: Dalal, M., Carberry, A., & Archambault, L. (2021). Developing a Ways of Thinking Framework for Engineering Education Research. *Studies in Engineering Education*, 1(2), pp. 108–125.

Submitted: 29 January 2020 **Accepted:** 23 September 2020 **Published:** 18 February 2021

VIRGINIA TECH. | VT Publishing

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