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Multiple Perspectives on Engaging Future Engineers

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BACKGROUND
Engaging future engineers is a central topic in everyday conversations on engineering education. Considerable investments have been made to make engineering more engaging, recruit and retain aspiring engineers, and to design an education to prepare future engineers. However, the impact of these efforts has been less than intended. It is imperative that the community reflects on progress and sets a more effective path for the future.

PURPOSE
The purpose of this article is to map a new innovation landscape for what it means to engage future engineers. This is a theoretically grounded divergent-thinking effort to enable a broader space of high impact innovations for engaging future engineers.

SCOPE/METHOD
A multiple perspectives methodology drawing from innovation, cross-disciplinary, and boundary work frameworks was used to make visible multiple facets of engaging future engineers. Scholars from diverse communities of thought and discourse were selected to present interparadigmatic perspectives, act as boundary agents, challenge and transform current ways of thinking, and illustrate new opportunities for engineering education innovation.

CONCLUSIONS
A new innovation landscape for engaging future engineers is needed, one that emphasizes epistemological development and social justice, new configurations on engineering thinking and connecting to the formative years of development, the entwinement of engineering knowing and being, and mutually informing consequences for opening up a broader space for innovation.We also need to adopt strategies and tools for using a multiple perspectives approach to better understand complex engineering education problems.

KEYWORDS
complexity, epistemological development, multiple perspectives

INTRODUCTION

"Engaging future engineers" is a topic that is front and center in everyday conversations on engineering education. As a fly on the wall we might hear: "Why aren't my students excited about being in class and spending the time needed to be successful?"; "Why aren't the graduates I hire ready to do 'real' engineering work?"; and "Why don't we see larger numbers and diversity among aspiring engineers?" Many of these conversations reflect concerns about meeting workforce needs, global economic competitiveness, capacities for responding to global challenges such as renewable energy and access to clean water, and persistence in engineering education. Ultimately, these concerns speak to issues of who becomes an engineer, what it means to be an engineer, and how to design an engineering education to prepare aspiring future professionals.

The engineering education community has made substantial, extensive, and long-term investments for "engaging future engineers." Examples include recruitment and retention programs from K-16 into graduate school (NSF-GSE, 2010), development of pedagogies of engagement (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011; Smith, Sheppard, Johnson, & Johnson, 2005) and curriculum resources (Flattau, Lal, Horin, Martinez, & Ford III, 2009), faculty development and effective teaching workshops (Felder & Brent, 2010; Felder, Brent, & Prince, 2011), and instruments and frameworks to conceptualize and predict student success and engagement (Astin, 1970a, 1970b; Chen, Lattuca, & Hamilton, 2008; Kuh, 2003; Ohland et al., 2008; Seidman, 2005). These examples correspond with prevalent themes in the *Journal of Engineering Education* that are relevant to "engaging future engineers"—assessment, curriculum and instruction, and retention (Borrego & Bernhard, 2011; iKneer, 2010). In parallel with these efforts has been a hundred years of assessing enrollment patterns, the nature and quality of undergraduate engineering curriculum and instruction, and identifying future needs of the profession (Layton, 1971; Mann, 1918; NAE, 2004, 2005; Noble, 1979; Sheppard, Macatangay, Colby, & Sullivan, 2008).

Considering this high level of investment, the overall impact on engaging future engineers has been remarkably less than anticipated or desired. Drawing on large multi-institution data sets there is strong evidence that academic *disengagement* increases steadily over an undergraduate engineering experience (Ohland et al., 2008) and that students struggle with career decisions into their fourth year (Stevens et al., 2008). In the United States, only a third of students who graduate with an engineering degree actively seek engineering jobs while over 60% do not limit or commit themselves to becoming future engineers (Lichtenstein et al., 2009; Ohland et al., 2008). Research suggests that engineering students are as persistent and engaged as other college students, however engineering programs are not effective in attracting students (i.e., "migrators") once they begin their college careers (Ohland et al., 2008). Regarding recruitment, improvements in the numbers of women and underrepresented minorities in U.S. engineering undergraduate programs have hit a plateau and are far below expected values (NSF, 2009). Studies in other countries suggest these trends are not unique to the United States (e.g., Baillie & Fitzgerald, 2000; Case, 2007; Godfrey, Aubrey, & King, 2010; Pears, Fincher, Adams, & Daniels, 2008).

Other evidence suggests that engineering education is holding onto approaches to problem solving and knowledge acquisition that are out of alignment with professional practice (Duderstadt, 2007; Sheppard et al., 2008). The education undergraduates experience emphasizes a focus on acquiring technical knowledge over preparing for professional practice, coverage of technical concepts over deep learning, narrow and discipline-focused programs, heavy workloads and a meritocracy of difficulty, and the use of laboratory and design experiences as "adjuncts" to deductive teaching strategies and structured problem sets (Litzinger et al., 2011; Sheppard et al., 2008; Stevens et al., 2008). This model of engineering education places technical problem solving at the core of "accountable disciplinary knowledge" (Stevens et al., 2008) while giving superficial attention to professional competencies. When talking about their educational experiences, engineering students see extracurricular experiences like internships as more representative of what it means to be an engineer than their in-class experiences, and describe a steep learning curve once they enter the workforce (Korte, Sheppard, & Jordan, 2008). Such an educational model is not likely to be effective in preparing engineering students to integrate knowledge, skills, and identity as developing professionals (Dall'Alba, 2009; Sheppard et al., 2008; Stevens et al., 2008).

As the *Journal of Engineering Education* celebrates its centennial year, it is important to not just look back but to look forward *broadly*. As a step forward, we assert four assumptions regarding scholarship on "engaging future engineers." The first is that past efforts have had merit, are rigorous and grounded, and have had some impact. If this is the case, a lack of progress is not a function of ineffective solutions but rather of ineffective problem formulation. This suggests that the current problem formulation space, and the associated set of effective solutions within this space, is only the visible tip of a large metaphorical iceberg. The second assumption is that the problem of "engaging future engineers" is complex, a "wicked" problem (Rittel & Webber, 1973) encompassing a complex network of ideas and communities of thought. If this is the case, gaining traction will require a multiple perspectives methodology that can characterize the complexity of the multi-faceted meanings and relationships associated with "engaging future engineers." The third assumption is that if a multiple perspectives methodology can gain traction on understanding these complexities, then the outcome of this process will be a more inclusive problem formulation space resulting in engineering education innovations with greater impact. Finally, if this methodology has merit and impact, then it can be useful for understanding other "wicked" engineering education problems.

In this paper, we present and use a multiple perspectives methodology to make visible the complexities of engaging future engineers, enable engineering education innovations along this theme, and uncover new opportunities that can lead to deep-diving, high impact and sustainable solutions. This involves (1) taking on multiple perspectives for "engaging future engineers" that may not be included or emphasized in current models, (2) encouraging divergent cross-disciplinary thinking to reveal a more inclusive set of effective strategies for improvement, and (3) creating conceptual dilemmas that challenge prior assumptions and reveal new ways to transform educational practices. A map metaphor was used to describe the outcomes of this process—a new innovation landscape of research and education questions for "engaging future engineers." Here, a map represents a problem formulation landscape that illustrates areas of emphasis (e.g., principles, values, tools), connections and interactions among these areas, and most importantly, boundaries that distinguish territories of ideas as places for trading, transformative conflict, and growth (Galison, 1997; Gieryn, 1999). As such, the map acts as a tool for enabling continual discussion and theory building around "engaging future engineers." An additional goal of this paper is to illustrate the use of a multiple perspectives methodology for understanding other "wicked" and intractable engineering education problems.

In the following sections we describe and present our approach and illustrate how this approach makes visible a broader landscape of strategies and tools for engaging students, increasing the number and diversity of aspiring engineering professionals, and understanding the relationships between what counts as engineering, how we design an engineering education, and who becomes or aspires to be an engineer.

A MULTIPLE PERSPECTIVES METHODOLOGY

A multiple perspectives methodology (Linstone et al., 1981; Mitroff & Linstone, 1993) was used to map a new innovation landscape for scholarship on engaging future engineers. As a mode of inquiry, this involves bringing together multiple perspectives across different paradigms of thought (e.g., rational, interpretivist, emancipatory) to develop insights into complex systems and enable unbounded systems thinking and transdisciplinary transformation (Mitroff & Linstone, 1993). This is a generative divergent-thinking process that seeks to narrow the gap between a model and reality (Linstone et al., 1981). Underlying features of this methodology include recognizing the interrelatedness and inseparability of perspectives within a complex inquiring system (Churchman, 1971), challenging implicit and explicit assumptions, and addressing the limitations of single-paradigm reductionist approaches (Linstone et al., 1981).

The outcome of this methodology is a meta-inquiring system that maps a landscape of multiple ways of knowing such as technical, organizational, and personal (Linstone et al., 1981). This is a space of conflict and confrontation, as different modes of inquiry interact to enable transformative knowledge. An added benefit of this methodology is that it aligns with practices for innovation (e.g., Johannson, 2006; Kelly & Littman, 2005), advancing knowledge (e.g., CFIR, 2005; Galison, 1997), linking research and practice (e.g., Turns et al., 2006), and cultivating cross-disciplinary communities of practice (e.g., Lave & Wenger, 1991; Wenger, McDermott, & Snyder, 2002). As an example, Kelly and Littman (2005) encourage the use of multiple perspectives to operationalize the devil's advocate, combat narrow and reductionist approaches, and enable innovation. Similarly, Case and Light (2011) explore multiple perspectives on research methodologies to encourage pluralism, expand the domain of questions used to inquire into complex systems, and explore new lines of questioning that delve deeply into a phenomenon.

Operationalizing a multiple perspectives methodology involves making decisions about ways of experiencing, selecting, and communicating diverse perspectives. For this paper, the reader is encouraged to explore different perspectives on engaging future engineers through a collection of co-existing "multiple perspective" essays written by scholars from different communities of thought and discourse (Swales, 1990). In this way, readers are afforded opportunities to "experience" a set of key ideas; by traversing the essays readers not only come into contact with different ideas but also different languages, values, modes of communication, and forms of inquiry. Some of these ideas may resonate and some may challenge assumptions and ways of thinking. This is an intentional multiple perspectives strategy to evoke connection, disorientation, and transformation.

Essay authors were given a standard set of instructions to ensure consistency: (1) use a conversational writing style and meet a 1,000 word limit, (2) describe how their community thinks and talks about issues associated with engaging future engineers, (3) challenge current perspectives, make visible alternate views, and suggest ways for improving engineering education, and (4) be a boundary agent by using conversational language, providing cues to key concepts and seminal bodies of work, defining important concepts for a lay audience (e.g., intersectionality, epistemology), and providing information on where to network with others in their discourse community (see Appendix, Table A1).

Two criteria were used to select perspectives for this paper. The first was to represent a space of possible dimensions as well as establish balance across dimensions (Linstone et al., 1981). The space of perspectives for "engaging future engineers" spans a continuum of

TABLE 1
Essay Author's Background, Context, and Discourse Communities

Author	Background	Context	Example Discourse Communities
Dias de Figueiredo	Computer Science Electrical Engineering	Portugal	IEEE; International Network for Engineering Studies; Philosophy and Engineering; Society for the History of Technology; Society for Philosophy and Technology
English	Cognitive Psychology & Mathematics Education	Australia	American Psychological Association; American Educational Research Association; Australian Association for Engineering Education; International Group for the Psychology of Mathematics Education; Mathematics Education Research Group of Australasia
Evangelou	Education Psychology	U.S. and Greece	American Educational Research Association; American Society for Engineering Education; European Early Childhood Research Association; Research in Engineering Education Network; Society for the Development and Creative Occupation of Children; Society for Research in Child Development
Mousoulides	Mathematics Education Science & ICT Education Educational Sciences	Cyprus	American Society of Engineering Education; European Association for Research on Learning and Instruction; European Society for Engineering Education; European Society for Research in Mathematics Education; International Group for the Psychology of Mathematics Education; Research in Engineering Education Network
Pawley	Industrial Engineering Women's Studies Chemical Engineering	U.S.	American Society for Engineering Education; Engineering Social Justice and Peace; International Network for Engineering Studies; National Women's Studies Association; Society of Women Engineers; Society for the Social Studies of Science; Society for the History of Technology; Research in Engineering Education Network; Women in Engineering Pro-Active Network
Schifellite	Sociology and Equity Studies in Education Biology & Psychology	Canada	Engineering Social Justice and Peace; International Society for the Study of the History; Philosophy and Social Studies of Biology; Society for the Social Studies of Science; The Canadian Sociological Association

TABLE 1
Continued

Author	Background	Context	Example Discourse Communities
Stevens	Cognition & Development, Education in Mathematics, Science & Technology Mathematics	U.S.	American Educational Research Association; Cognitive Science Society; European Association for Research on Learning and Instruction; International Society for the Learning Sciences; International Society for Cultural Research & Activity Theory; Society for the Social Studies of Science; Society of Applied Anthropology
Svinicki	Experimental & Developmental Psychology	U.S.	American Educational Research Association; American Psychological Association; Association for the Study of Higher Education; Professional and Organizational Development Network in Higher Education
Trenor	Materials Science & Engineering	U.S.	American Educational Research Association; American Society for Engineering Education; Society of Women Engineers; Research in Engineering Education Network; Women in Engineering Pro-Active Network
Wilson	Education Electrical Engineering Mechanical Engineering	U.S.	American Society for Engineering Education; IEEE Circuits and Systems Society; Special Interest Group—Computer Science Education; National Environmental Health Association

learning and development (e.g., childhood development, educational psychology, design of learning environments, professional development), global contexts, disciplinary-specific education (e.g., science, math, and engineering education), and social and philosophical dimensions including issues of race, class, and gender. Each of these represents a community of thought and practice that intersects with engineering education on topics of engagement and learning to become a future professional. The second criterion was to encourage divergent thinking and combat reductionism into a single paradigm (Linstone et al., 1981): there should be an interparadigmatic mix of perspectives with a goal of having at least two radically distinct disciplines of knowledge and systems of inquiry. For this paper, an example would be differences between social justice and educational psychology perspectives.

A multiple perspectives approach can be jarring for those accustomed to a single paradigm perspective (Linstone et al., 1981). It involves experiencing different languages, modes of communication, value systems, and inquiry techniques (Adams, Forin, Mann, & Daly, 2009; Borrego et al., 2006; Lattuca, 2001; Klein, 1990, 1996). It also involves being willing to challenge personal perspectives to make way for transformative learning (Adams, Forin, Srinivasan, & Mann, 2010). Essay authors were strategically recruited based on their domain expertise and their capacity for being cross-disciplinary "boundary agents" (see Adams et al., 2009, 2010; Gieryn, 1999) with experience working at the interface of different perspectives. As shown in Table 1, essay authors have training in multiple disciplines and participate in and publish across multiple discourse communities and cultures. This illustrates capabilities in translating across perspectives, being an "activist broker" (Kahn, Wolfe, Quinn, Snoek, & Rosenthal, 1964; Organ, 1971), and attending to differences in language, ways of knowing, modes of communication, and values.

The following sections represent multiple perspectives on engaging future engineers. Individual authors are identified in the title of each essay, and the set of essays are organized by themes of "engaging," "future," and "engineers." Each emphasizes a particular theme while speaking across themes more broadly. As an exercise for enabling innovation, we ask the reader to experience each perspective and to be open to different ways of thinking and communicating to imagine a new innovation landscape for engaging future engineers.

"ENGAGING"

The following three essays make visible the different dimensions of engagement. In the first essay, a scholar from educational psychology and professional development focuses on the role of building connections in helping learners develop rich networks of knowledge as both a marker and motivator for deep engagement and adaptability in a changing world (see Litzinger et al., 2011). In the second essay, a scholar from electrical engineering and education focuses on the role of affect (see also Litzinger et al., 2011) in mediating performance and engagement in formal, informal, and workplace settings. In the third essay, a scholar from the learning sciences puts forth an account of engineering as socio-technical and argues for a shift in how engineering is viewed and experienced. Each author explores the consequences of not including these ideas in terms of who becomes an engineer, how aspiring engineers navigate an engineering education, and what it means to prepare engineers for a world of increasing complexity and flux.

Marilla Svinicki—Creating Connections is the Key

One of my professional mentors, who was an engineer, often described his own education as becoming an expert in vacuum tubes. Just after he graduated, the transistor was invented and the world of engineering changed forever. In the fast moving world of technology and innovation, educators almost despair at the difficulty of preparing their students to function effectively and creatively in the world they are about to face. Be honest. By the time your engineering students finish their bachelor's program, what they know is probably out of date or soon will be. What is an engineering educator to do?

As a psychologist and an educator I can sympathize with these engineering faculty since in psychology and education, nothing *ever* stays the same; change is a constant. As a result, our goal in educating future professionals is to emphasize connections: between the old and the new, between the abstract and concrete, among the ideas and principles of the field, and with their instructors to adapt to the ever-changing world of learning.

I've chosen five types of connections that almost everyone in education and psychology agrees promote more efficient learning and the ability to adapt to a changing world.

They are derived from both real experience and basic research into learning. They work whether you are teaching someone else or learning on your own. They also apply across disciplines.

Connections between the new and the old. The basic process of learning, both at the behavioral and the neural levels, is building connections between existing knowledge and new knowledge. This is what happens in the brain: new neural connections are made to existing structures and are the bases for learning. At the macro level, we learn by connecting what we are learning to what we already know. What does this imply for teaching? Instruction should build on the learners' prior knowledge and understanding, either through direct illustration (e.g., "here is a computer simulation of a heart at work") or through analogical examples (e.g., "the heart is like a pump"). As learners experience more and more examples, they learn to look for these kinds of comparisons to facilitate understanding. The learners use everything they know about the old understanding to support new understanding and extrapolations (e.g., "if the heart is like a pump, something must control the flow. What structure or process might that be?").

Connections between the abstract and the concrete. As much as people with Ph.D.s love theory and abstractions, we must recognize that a beginning learner does much better starting with concrete examples. The basis for this lies in the principle of connecting old to new. Familiar concrete examples are old knowledge, which provides the learner with a guide to understanding the new, abstract representations of the world. Concrete examples are easier to visualize, have been encountered at some point in the learner's past, and serve as touchstones for evaluating understanding. As the learners try to understand the abstract representation, they can test that understanding by visualizing what would happen in the real world if it were true and decide that it is consistent with their experience. What does this mean for teaching? Educators should look for examples in the students' experiences that can be used to illustrate theories and principles. Otherwise the students will revert to memorizing the principle without seeing how it relates to their current or future worlds. Not only does this diminish learning, it also lowers motivation to learn.

Connections between understanding and applying. Learners do not really understand until they can apply that understanding to a personal demonstration of the learning. This is actually the principle behind the effectiveness of active learning. It is based on the fact that learning requires feedback, and interaction with the environment provides the best and most generalizable feedback. Observing someone else solving a problem results in a shallow understanding (e.g., "It all seemed so clear when the instructor did it"). Solving it yourself makes all those connections real. The implications for teaching are fairly obvious, and yet we frequently ignore them. We act as if once we have said *it*, students have understood and learned *it*. In reality it isn't until they have been required to do *it* that learning occurs.

Strive for structural connections, not just surface similarities. This idea takes the principle of learning through connections to a new level. The best, most adaptive type of learning ties things together in a system that not only creates a space for existing learning, but allows learners to anticipate where not-yet-discovered ideas should fit. Our brains are hardwired to look for patterns in what we experience. Those patterns become the basis for future action and learning. Of all the principles of learning, this is the one that does the most to allow a learner to adapt to new situations and come up with new ideas. An empty cell in a matrix is a problem begging to be solved. In teaching, the structure of a concept and how it relates to other concepts should be provided before going too far into the components. Using such beginnings as flow charts or decision diagrams makes the underlying connections more apparent. In the end those structural connections are what learners use to organize their understanding.

Be a model of the engineer that you want your students to be. Perhaps the final connection in learning is not between ideas, but between people. A very strong source of learning in many animal species, especially humans, is observation and imitation of others. Through this we learn not only knowledge and skills, but also values and attitudes. A teacher's greatest strength and possibly greatest challenge is that he or she is teaching all the time, whether intentionally or not. If you want your students to be creative, lifelong learners, that is the face you should have on as you interact with them. Everything you do or say has the potential to impact how your students understand what it means to be an engineer. So perhaps the most potent source of learning is not from the lectures, the books, the homework or the projects or exams, but from the teacher; a very sobering thought.

Denise Wilson—Affective Outcomes as the Great Mediators of Engagement

Yet another important connection educators should strive to emphasize in the classroom is the connection between the mind and the heart through affect. Affective outcomes represent the roadway by which present and future engineers can cross the bridge between science and society (through the effective design and application of technology) and move from the periphery to the center of the community of practice in the globalized society of the twenty-first century.

Some affective influences change readily, producing wide swings in engagement, while others are much more stable, changing slowly over time. Feelings of belonging, for example, can change over short time scales as classrooms and courses change each term. In one classroom, a student may feel a strong sense of belonging via substantial local relational bonds and support networks (Baumeister & Leary, 1995); as a result, the student can engage far more emphatically and show dramatic improvements in academic performance than in a classroom where there is lower sense of belonging (Wilson, 2008). Self-efficacy, on the other hand, is more stable in a range of classroom environments, demonstrating no significant differences across engineering disciplines (Concannon & Lloyd, 2008). Identity forms much earlier in life and is relatively stable over adult life. A young aspiring engineer who does not develop an identity as an engineer is far more vulnerable to external influences in persisting than one who has developed a strong identity and is likely to stay in the field "no matter what." Similarly, calling and vocation are by their very definition, stable over the long term (Dik & Duffy, 2009). Calling, vocation, and identity all serve as stabilizers in turbulent and dynamic instructional and professional environments.

The complex role that affective constructs play in influencing engagement and ultimately academic and workplace performance may be best understood by looking at a story of an individual engineer in the context of two very different engineering environments (Wilson, 2008). Consider Bethany, an under-represented minority female, who was completing a civil engineering program at a large research-intensive university. During her program, she took a term off-campus to participate in a service learning project in a disaster recovery zone. Bethany had a GPA of 3.0, neither of her parents attended college, and she had ambitions to attend graduate school in engineering. She often expressed feelings of being overwhelmed in her engineering classes, but remained intrigued with course topics. She felt capable, but limited in her ability to apply the skills learned in her undergraduate engineering experience. Her sense of belonging compared to that of her peers in engineering at her home university was very low. She confessed that she did not think about her fulfillment and was unable to identify it when asked, and did not feel connected to her peers or faculty: "That's just the way it is for minority students. I'm used to it." When on campus, she felt less capable than her peers and her academic engagement was at a level consistent with keeping her head above water.

However, during a service learning program, where essentially almost every participant is an outsider or minority, Bethany showed drastic improvements in affect: a substantial improvement in sense of belonging and significant improvements in her impressions of feeling technically competent and socially comfortable. On this project she performed well academically and was highly engaged in her community. She was heavily invested and highly inclined to take initiative and a leadership role, indicating overall a high level of engagement. Her integration of hybrid sources of information into her culminating term paper was unusual among her peers. She completed her term paper, with little assistance from faculty, integrating information from a wide variety of sources to understand, in a balanced and realistic manner, ways to improve transportation systems in crisis situations. Overall, Bethany's academic performance for the mainstream course within the program was ranked second among her twelve peers. Bethany's case clearly illustrates the impact of improved affective outcomes on performance. Using a bridge analogy, these affective outcomes effectively pave the roadway for smoother travel; where people, like Bethany, may have once travelled a gravel road prone to potholes and limited options, now have a smoother and wider avenue for moving through.

The drastic change in Bethany's experience begs the question: How can we enable comparable increases in affective outcomes and technical competence when students are on campus in classrooms? On campus, the affective construct of faculty-student relatedness has proven highly correlated with belonging and academic fulfillment (Chen et al., 2008; Lee & Wilson, 2006). In theory, individual faculty can scaffold positive affect in the classroom; in practice the average human being can only successfully carry on 3-4 meaningful relationships at one time. Thus, it may be impractical to make drastic improvements in on-campus affective experiences of engineering students through building faculty-student relatedness. A practical solution is to diffuse the relational capacity of the classroom by involving more people. Complicating matters further, a positive affective environment in an undergraduate experience does not provide a complementary lasting impact. Unlike cognitive development, problem-solving and critical-thinking skills do not typically decline in the workplace the road of affect is continually in need of repair and upgrading to keep engineering professionals engaged and contributing in the workplace. In fact, many women, even if they have positive experiences in college, burn out in their mid to late thirties, leaving engineering primarily for affective deficits in the workplace (Hewlett, 2008) including feelings of intimidation and isolation. As such, in engaging future engineering students, university faculty and administrators must also consider training students in awareness of affect (emotional intelligence) and providing tools for helping graduates influence affect among peers in the workplace:

> Emotions in the workplace are real. They are not, as was believed in the 1950s, just annoyances which deflect us from objectivity. They are the essence of the human experience which are manifested in that context which consumes most of our life's energies—our jobs. (Muchinsky, 2000)

Thus, as engineering educators, we cultivate both the scientist (theory) and practitioner (design) in engineering students, and are obligated to convey the shared relevance of emotion: professionals in higher education must not only pave the road but also train students in upgrading and maintaining that road when working as future engineering professionals. Affective factors, while they do not allow us to create an engineer out of an artist, allow us to empower and strengthen aspiring and future engineering professionals to pursue, succeed, and find fulfillment in engineering. Thus, investment in instructional practice to improve affect in the immediate classroom and to teach students the importance of influencing affect in their own communities of practice is an essential part of engaging the future engineer into a lifelong career that is both fruitful and fulfilling.

Reed Stevens—Toward a Socio-Technical Engineering Education

Something I learned from five years of studying the experiences of undergraduate engineering students is that engineering education has a funny, maybe even neglectful relationship to…people. I mean this in multiple senses. My colleagues and I came across this early and often in interviews with students. One woman worried even back in her freshman year that engineering was not for her because she saw herself as a "people person" (Stevens, O'Connor & Garrison, 2005). We heard similar concerns in other interviews. Engineering on one side, people on the other. Throughout our research we found that students had vague images of what engineering is, but whatever it was, it did not have much to do with people.

We found that as students made their way deeper into engineering programs, they developed increasingly strong us/them views about other college students and some strongly held views about the limited value of academic disciplines whose scholarship pays attention to people. These disciplines include psychology, sociology, anthropology, history, and the interdisciplinary field I identify with—the learning sciences. At one institution in our study, "we," the engineers, were the "techies" and "they" were the "fuzzies."

For the sake of this essay I assert that students came to the view that engineering is systematic *technical work*. If you read from the history of engineering education, this was indeed the image engineering education sought as it quite legitimately tried to put distance between itself and the "maintenance engineer" and to gain recognition as a profession. There are few straighter paths to this than the mantle of hard science. Now, of course, engineering is technical work, recognizably so. But I want to suggest it ought to be reimagined as something more—as *socio-technical* work. In what follows I argue for this image of engineering education and lay out a sketchy proposal for how to move toward it.

"You've got your social in my technical; you got your technical in my social!" I encountered the odd hyphenate "socio-technical" early in my career. It comes from Science and Technology Studies, a field that has involved "follow[ing] scientists and engineers through society" (Biagioli, 1999; Latour, 1987) to examine how the practices of these professionals line up with the images that textbook pedagogies and philosophers espouse. I have adapted this approach in my own work, trying to understand how professionals learn and "become" whatever professionals they become. There are good reasons for doing this: if a leading goal is to prepare young people to be professional engineers, then the guardians of the educational experience ought to keep a steady focus on what is happening (and changing) in professional engineering. It is all too easy for what goes on inside educational institutions to drift away from what goes on outside of them. Registering this drift does not mean mimicking professional practices in educational experiences, but rather that these practices ought to be in clear view when establishing policy and undertaking reform.

I started taking the "socio-technical" seriously in research that compared activities in classrooms to activities in professional workplaces, including engineering. I found it hard to disentangle the people from the technical things (cf., Hutchins, 1995). My struggle was:

> Technology is never purely technological: it is also social. The social is never purely social: it is technological. This is something easy to say but difficult to work with. So much of our language and so many of our practices reflect a determined, culturally in-grained propensity to treat the two as if they were quite separate from one another. (Law & Bijker, 1992, pp. 305–306)

In my view, engineering education is a culture in which this propensity to separate the technical and the social—the humans and the non-humans—is very deeply ingrained. It is beyond the scope of this short essay to show how interwoven people are with any particular engineered product, structure, or system, or how completely one will find humans and technologies entangled at every project stage—from initial conception to iterative refinement, dissemination, intended, and unintended use. On these points, I invite readers to explore the concept of "heterogeneous engineering" (e.g., Law, 1987; Suchman, 2000). "The construct of heterogeneous engineering is meant to underscore the extent to which the work of technology construction is…also the work of organizing" (Suchman, 2000, p. 324). While engineers organize a network of technological elements, they also organize human/institutional actors. For example, consider Suchman's study of a bridge project in which she shows the many non-technological agents who were relevant to the outcome of the project: federal agencies, state and local governmental officials, regional transportation committees, home-owners, toll bridge workers, and so on.

In my work, I have shown that practicing engineers literally learn to "see" the relevant concerns of these multiple actors (e.g., clients, city officials, and their own firm's profit watchers) in their working representations (e.g., plans and models), and this distinguishes their professional expertise. Novices or newcomers do not see these concerns as readily and do not balance them as effectively (Stevens & Hall, 1998). The way this expertise develops comes from engineers moving *between* the representations and interactions with these varied stakeholders. This is a notably different image of developing representational expertise than the one from cognitive science, which emphasizes that novices attend to conceptually superficial features of textbook-like problems while experts tend to conceptual deep structures. In comparison, our studies show that experts in practice learn to attend to the consequential *social structures* that can be read from representations.

A re-imagined engineering education starts from two basic principles: (1) the socio needs to be balanced with the technical and (2) it should be as hard (or as easy) to pull apart the socio from the technical in the educational experience as it is in the realization of successful engineering projects. Below are three examples of what a socio-technical engineering education might look like.

Case-based studies of heterogeneous projects. Engineering students ought to see and analyze case-based materials of heterogeneous engineering projects early and often in their educational careers to learn how the technical is shaped by the social and how much the technical object can reshape the social. Early courses in most engineering education programs, like mathematics, chemistry, and physics are largely prerequisites in cognate technical disciplines. These "outsourced" experiences do not do engineering any favors in terms of helping students understand the real work of engineering or to become identified with it (Stevens, O'Connor, & Garrison, 2005).

"Follow the object" fieldwork. Engineering students should have at least one experience in which they participate in fieldwork that follows the lifespan of an actual technical object, which begins in the minds of people, finds its way onto paper and into computer-based representations and slowly takes material form. This could be embedded in traditional co-op or internship experiences, in which students "follow the object" through phases of an engineering project and see how the technical object in question (e.g., a microchip, a robotic vacuum, or a water system) is shaped and deflected by the many humans with whom it comes into contact.

Design experiences that multiply the relevant actors. In senior capstone experiences students get a taste of interacting with relevant actors that have input to the design, but this is often experienced as a dramatic shift that triggers serious growing pains and no small amount of resentment (Stevens et al., 2008). Students feel, perhaps legitimately, that the rug has been pulled out from them, "Where are my problem sets?"; "Who are all these people I have to work with and for?"; "If this is engineering, why was I not doing this before?" While capstone projects are a step in the right direction, they do not go far enough; they do not simulate enough of the relevant actors and the moments in a project when these can intrude, influence, and generally deflect the technical object. Having these kinds of experiences early in an engineering experience can help students in their senior year see for themselves how much their combined socio-technical knowledge has led them to successful engineering projects.

I have favored proposals that give some flavor and direction and do not require taking too much out of a tightly packed curriculum, but rather rethinking the experiences students are already having. What I am arguing for is a shift in how engineering is viewed and experienced. Many years of being fascinated by the real work of engineers has led me here. It does not seem fair that I get to see how engaged, social, material, and consequential engineering is but engineering students do not. I wonder what an engineering student with these understandings would do, would make, would imagine.

Finally, a re-imagined socio-technical engineering education can help ameliorate many of the problems that engineering education sees in itself and many we have identified in our studies. It surely would provide a more welcoming home for "the people person." It would certainly help students better understand that a good reason to do engineering is more than good money and comfortable lifestyle (Stevens, Amos, Jocuns, & Garrison, 2007); it can help convert the inspirational slogans of "social good" we heard among students to actual experiences because the social impacts of engineering, when they are good, would be plain to see. A parting thought: a re-imagined socio-technical engineering education might possibly have an unintended consequence—significant innovation, because new design and analysis paradigms can as we know have these effects.

"FUTURE"

The previous section explored different dimensions of "engaging" that make visible aspects that may have fallen off our collective radar or never made it to the map. They also mark shifts in thinking from unconnected knowing to connected knowing, a focus on mind as separate from heart to an integration of knowing and belonging, and from a separation of the social from technical engineering to an inseparable entwinement of socio-technical engineering. In this section, we move the frame to the "future" and present two essays from insiders working in international P-12 contexts who emphasize a connection to the formative years of development and identity formation. In the first essay, two scholars from mathematics education explore the role of integrating engineering into elementary curriculum to make visible how encounters with models and situations of uncertainty develop engineering thinking. In the second essay, a scholar from childhood development and engineering education explores the significance of children's interactions with artifacts to reveal early precursors to engineering thinking that capitalize on experimentation, discovery, curiosity, and agency for self-initiated learning.

Nicholas Mousoulides and Lyn D. English—Providing Engineering Experiences to Elementary School Students

The need for young scholars who will study engineering at the university level and will be involved in the next generation of innovative ideas that advance our society is greater than ever (National Academy of Sciences, 2007). Recent studies reveal waning student interest in engineering, a lack of diverse representation, and low persistence of current and future engineering students (Dawes & Rasmussen, 2007; Cunningham & Hester, 2007). These findings further underline the importance of introducing engineering education at the elementary and secondary school level.

Among the core questions that are posed in related research in engineering education for young learners are those pertaining to the nature and components of engineering thinking for elementary school children such as how engineering experiences can be integrated within existing school curricula, and which engineering contexts are meaningful, engaging, and inspiring to students (Dawes & Rasmussen, 2007).

From the lens of mathematics and science, engineering provides a rich source of meaningful, real-world problem situations that capitalize on and extend students' existing mathematics and science learning. We give consideration here to engineering as a problem-solving domain within the mathematics and science curricula and address how mathematical modeling complements and enriches engineering design processes in solving engineering-based problems. This essay presents an example of the integration of engineering education in elementary school mathematics and science curricula, namely through Engineering Model Eliciting Activities (EngMEA) (e.g., Litzinger et al., 2011; Mousoulides & English, in press; Zawojewski, Hjalmarson, Bowman, & Lesh, 2008).

Among engineering education's aims for young learners are the understanding and appreciation of the problems engineers face, how engineering shapes the world utilizing important ideas from mathematics and science, and how it contextualizes mathematics and science principles (Dawes & Rasmussen, 2007). Integrating appropriate engineering experiences within the elementary school mathematics and science curricula is important for a number of reasons and can: (a) help students appreciate how their learning in mathematics and science can apply to the solutions of important real-world based engineering problems, (b) lead to better preparedness for senior subjects, (c) highlight the relevance of studying mathematics and physical sciences, and (d) help students appreciate the usefulness of the various fields of engineering and the role of the engineer in the society (Zawojewski et al., 2008). Students learn how to apply an engineering design process in solving real-world problems; they learn to think creatively, critically, flexibly, and visually, and to troubleshoot and learn from failure. From the teacher perspective, considering that the majority of teachers have no education about engineering concepts and thinking, there is a strong need to provide professional development and appropriate resources to scaffold their understanding and pedagogical strategies to effectively integrate engineering experiences within the elementary mathematics and science curricula (Mousoulides & English, in press).

Here we address one of the means for designing and implementing engineering experiences within the mathematics and science curricula, namely, a models and modeling approach (Lesh & Doerr, 2003; Zawojewski, et al., 2008). In adopting the models and modeling approach, real-world engineering situations are presented to students. These Engineering Model Eliciting Activities (EngMEAs), offer students opportunities to repeatedly express, test, and refine or revise their current ways of thinking as they endeavor to create a structurally significant product—structural in the sense of generating powerful mathematical and engineering constructs. In EngMEAs, students undergo a cyclic process of interpreting the problem information, selecting relevant quantities, identifying operations that may lead to new quantities, and creating meaningful representations (Lesh & Doerr, 2003; Mousoulides, Sriraman, & Lesh, 2008). These cyclic processes of modeling and engineering design processes are very similar: (a) a problem situation is interpreted through understanding the problem and the system to be modeled, (b) initial ideas (initial models, designs) for solving the problem are called upon, (c) a fruitful idea is selected and expressed in a testable form, (d) the idea is tested and resultant information is analyzed and used to revise (or reject) the idea/model, (e) the model is evaluated under conditions of its intended application, and (f) the model is documented throughout the development process (Mousoulides & English, in press).

The Water Shortage activity (Mousoulides & English, in press) is an example of an EngMEA for elementary school children. In this activity, students are sent a letter from an imaginary client, the Ministry of Transportation, who needs a means of (model for) selecting a nearby country to buy water from, using tanker ships (shortage of clean water is a major problem in a number of countries across the globe). The letter asks students to develop such a means, using the quantitative and qualitative data provided (e.g., oil cost, tanker capacity, port facilities) from four countries on which to test their ideas, and also retrieve additional data from the Web. Engineering problems such as *The Water Shortage* problem are designed so that multiple solutions of varying mathematical and scientific sophistication are possible and children with a range of personal experiences and knowledge can participate. The products children create are documented, shareable, reusable, and modifiable models that provide teachers with a window into their students' conceptual understanding. Furthermore, these modeling problems build communication (oral and written) and teamwork skills, both of which are essential to success in engineering (Mousoulides & English, in press).

Engineering modeling activities developed from a models and modeling perspective can take students beyond their usual problem-solving experiences to encounter situations that require substantial interpretation of the problem goal and associated complex data (Mousoulides, Christou, & Siriraman, 2008). The elementary school curriculum provides ideal opportunities for introducing students to fundamental engineering ideas and principles. EngMEAs can engage students in exploring fundamental engineering ideas and principles, and furthermore develop their engineering problem-solving skills. We consider it imperative that young scholars develop the curiosity and drive to learn how engineering shapes their world and supports so many of our society's needs and to consider themselves as future engineering students.

Demetra Evangelou—Precursors to Engineering Thinking in Young Children

Declining engineering enrollments and waning enthusiasm for engineering studies and careers are consistent observations in the advanced industrialized nations (Duderstadt, 2008; National Academy of Engineering, 2005). Are these observations worrisome, reversible, or symptomatic of deeper problems? Answers to such questions may come from the emerging field of *developmental engineering*. A growing number of studies point to the need for improving our understanding of what is entailed in the precursors of engineering thinking, particularly in early childhood education (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Bers, 2006; Brophy & Evangelou, 2007; Evangelou, Dobbs-Oates, Bagiati, Liang, & Choi, 2010; Evangelou, Habashi, Ngambeki, & Graziano, 2008; Habashi, Evangelou, & Graziano, 2009). Intellectual resources drawn from a diversity of disciplines can generate new knowledge, articulate new approaches, build new programs, and improve the process through which modern society prepares the next generation of engineers. If we think of engineering as civilization, developmental engineering can be thought of as its cradle.

By the time students get to the university they have fairly well-established likes and dislikes about engineering. Some of this is attributed to a pop culture frenetically obsessed with fantasy and entertainment. Some can be attributed to family influences, yet a lot of it seems to boil down to what happens in early schooling; *when* and *where* and *what-was-seen* when developmental windows were opened for a young mind to peak into the human-made world (Committee on Early Childhood Pedagogy, 2001; Preschool Curriculum Evaluation Research Consortium, 2008).

Engineering education represents a broad range of interests and applications that, although evolving, appears to be pivoted in the age-old relation of people with artifacts. The relation of humans with human-made things, artifacts (Tomasello, 1999) as studied in disciplines such as anthropology and the social sciences, and the generated knowledge finds significant applications in man-machine interfaces, automation, computer learning, and consumer product design (Norman, 1988, 2004). Paradoxically though, it is not as prominent in the education of engineers, and is nearly absent in pre-university education.

Developmental engineering focuses on the systematic investigation of early childhood education precursors to engineering thinking. It is multifaceted and complex and brings distinctive knowledge about the *what* and *why* and *how* of human-made things in custom-made ways. It fosters abstract thinking in developmentally appropriate ways. It engenders the potential for addressing most significant school problems and can revolutionize curriculum. But it can also present us with challenges as great, if not greater, than the challenge to Science Education presented by Sputnik in the late 1950s (Consortium for Longitudinal Studies, 1983). We must explore and capitalize on such challenges and opportunities by introducing pedagogical innovation and demonstrate how engineering thinking can be a complete vehicle for learning in modern society.

The ideas outlined here are intended to summarize what we know, what we need to learn, and possibly even what we may want to do in our efforts to understand how early education and engineering can identify common research threads in developmental engineering. Understanding the nature of developmental engineering begins with realizing that early experiences are formative experiences. Plethora of empirical data (National Research Council and Institute of Medicine, 2000) ascertain that early childhood education (preschool to around third grade) constitutes a distinct period of life during which development and education are highly interactive. Early exposure to the wrong stimuli (Preschool Curriculum Evaluation Research Consortium (PCERC), 2008) can result in damaged dispositions toward some of the desirable qualities and characteristics as perceived from an engineering perspective. We must therefore construct and carry our carefully designed studies that inform about the long-term effects of engineering related early experiences and subsequent school behaviors and academic achievement (Gellman, 2007; Siegler 2007).

Understanding the nature of developmental engineering also involves recognizing the complexity of interactions between environment and organism (National Research Council and Institute of Medicine (NRCIM), 2000). In the past, early childhood education has benefited from large comprehensive studies that were designed to assess the effects of particular early childhood education approaches to the development and education of children from at risk groups. These intervention studies known as the Head Start studies of the 1960s (Barnett, 2008; Consortium for Longitudinal Studies, 1983; Oden, Schweinhart, & Weikhart, 2000) despite their methodological limitations, have pointed to significant effects resulting from the various interventions. If early experiences are formative experiences, and if development can be affected by education, the design and integration of comprehensive early engineering curricula should be explored.

While the question of the nature of early engineering curricula is an empirical one, our understanding of some of the principles involved is sufficiently developed to permit some recommendations. They are learning principles derived from a developmentally appropriate constructivist perspective (National Association for the Education of Young Children (NAYEC), 2009; Vygostky 1962, 1979). They assume that learning in school results from a carefully planned and appropriately designed setting of structural and process characteristics that assist the learner in *self-initiated* but adult-supported learning.

We envision a learning environment constructed to reveal the depth and beauty of engineering as the process of *creating civilization* in ways that are accessible and inviting to children. Observing children in their natural environment reveals the inner need and innate propensity for exploration, intervention, understanding, and manipulation of the surrounding natural and artificial world. In our studies, we see children as young as 4 years old build on their intuitive understanding of the material, blocks, and constructing structures that resemble a design process every step of the way (Brophy & Evangelou, 2007; Evangelou, et al., 2010). While this is not necessarily an argument for including engineering in the early years it is a hypothesis about naïve engineering that we can work with.

Integrating early engineering education in the K-12 system will require extensive documentation of current practices and identification of points of intervention based on the following developmental principles:

- Early engineering curricula should capitalize on children's naturally occurring curiosity and agency for self initiated learning (Katz & Chard, 2000; Roth & Lee, 2007).
- Curricula should be designed to encourage exploration, inquiry, and design within the developmentally and culturally appropriate boundaries of the learner (Gelman, 2007; Vosniadou, 2001; NAEYC, 2009).
- Teachers, as crucial partners actively involved in the scaffolding of children's learning, would require special training and support in incorporating the novel content knowledge (Roth & Lee, 2007; Tomasello, 1999).

Early engineering education is the beginning segment of a continuum that in broad terms represents human relations vis-à-vis the human-made artifacts of civilization. To follow its extension to life span time scales is not simple. To bring it in the curriculum presents its own complex sets of challenges (Sullivan, 2004). Understanding how and where early engineering learning originates would help us produce better-trained engineers and reproduce and enhance our engineering knowledge across the boundaries of generations (Pramling & Kagan, 2008).

"ENGINEERS"

The previous section explored different dimensions of the "future" that challenge ideas about engaging students in engineering thinking early in their formative years. They also mark shifts in the current landscape about engineering education in P-12 contexts from an add-on experience to integrating engineering ways of thinking and interacting into existing curriculum and structures, and from seeing engineering as a vehicle for learning mathematics and science towards seeing engineering thinking (dealing with uncertainty, interacting with artifacts) as a complete vehicle for learning in contemporary society. In this final section, the frame moves to "engineers" through three essays that examine the elephant in the room—engineering and engineers—challenging the boundaries we have constructed on what counts as engineering and how this shapes who aspires to be an engineer and what it means to prepare professional engineers for a pluralistic and global society.

In the first essay, a scholar from computer engineering and the philosophy of engineering maps out a coherent transdisciplinary epistemology of engineering and describes how this broad space allows aspiring engineers to configure their own commitments to engineering and understand the importance of learning how to collaborate and create collective value within this complex space. In the second essay, a scholar from sociology and equity studies broadens the idea of "engagement" to emphasize epistemological development as an ability to respect and engage with multiple competing views while being socially aware actors within the communities engineers serve. In the third essay, scholars with cross-disciplinary training in engineering, women's studies, psychology, and sociology make visible the complexity of connections between what counts as engineering and who gets to become an engineer as well as variations in the experiences of aspiring engineers living at the intersection of multiple social dimensions. As a collection, these essays mark shifting territories of thought and impact: a shift from reductionism to pluralism as a place for transformation, a shift from an economic argument to a social justice argument as a reason and method for engaging future engineers, an awareness of "engineering" as a social construction that can support multiple perspectives, and an expansion from focusing on individuals to focusing on social organizations. Each also speaks to how engineers live and work at the intersection of different ideas and identities.

Antonio Dias de Figueiredo—The Epistemology of Engineering

This is the voice of a professor of computer engineering who devoted many years to the study and teaching of the nature of engineering as a profession and as a body of knowledge.

There is no single minute in our lives that is not affected by the work of engineers. The buildings where we work and live, the highways we drive on, the bridges we cross, the electricity that powers our days and nights, the computers that extend our minds, the networks and phones that empower our communication, all the technical systems and artifacts (real and virtual) that populate our present have been designed by engineers. However, the image of engineers in the public opinion is poor. How can we engage a future generation of engineers if we are unable to excite their imaginations? Is engineering in search of an identity?

The lack of social and intellectual respectability of engineering is an old problem. Lewin (1983) explains it as resulting from the "lack of understanding of what constitutes engineering, the confusion between engineering and science," and "the lack of an identifiable engineering philosophy." In his view, "whilst engineering is seen simply as a confluence of science and industrial practices, a view still strongly held in schools and universities, engineers will always be considered as second-rate scientists." Layton (1986) also highlights the lack of an ideology of engineering capable of recognizing that most engineering practices are better understood in terms of design than of science. Although the place of design in engineering seems to be moving to the forefront (Lewin, 1979), the ignorance of other dimensions—besides science and design—and the lack of a coherent epistemology capable of aggregating them all damages the image of engineering and its professional identity.

Theodore Von Kármán, a famous mathematician and aeronautical engineer, when asked about the difference between scientists and engineers, replied: "Scientists discover the world that exists; engineers create the world that never was." This is undoubtedly the beginning of a clarification. However, there is much more to the essence of engineering than the difference between a scientist and an engineer. To characterize this essence, we describe engineering as consisting of four dimensions linked by a relationship of transdisciplinarity, as shown in Figure 1. These dimensions are: the basic sciences, the human sciences, design, and the crafts (Figueiredo, 2008).

The dimension of the basic sciences views engineering as the application of the natural and exact sciences, with logics and rigor, through analysis and experimentation. The major aspiration in this dimension is the discovery of first principles.

The dimension of the human sciences sees engineers not only as technologists, but also as social experts, managers, and businesspeople who recognize the social complexity of the world and markets they act upon and of the teams they belong to (Cross, 1952; Layton, 1986). The creation of social and economic value and the belief in the satisfaction of end users emerge as central values in this dimension.

The design dimension sees engineering as driven by design (Lewin, 1979). It values systems thinking much more than analytical thinking. Its practice is founded on holistic, contextual, and integrated visions of the world rather than on partial visions. The importance of design in engineering calls for special awareness about the epistemology of

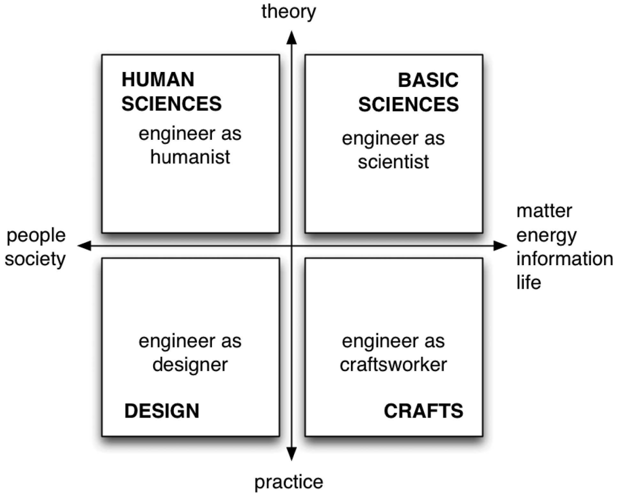

FIGURE 1. The four dimensions of engineering (see Figueiredo, 2008).

design, which has evolved in the last decades from a strong positivist tradition, between the 1920s and the 1970s, to a constructivist reaction against science-inspired design methodologies (Cross, 2001; Figueiredo & Cunha, 2006). An important contribution to this debate is the recent description of systems design as made up of four categories (Gasson, 2006). The first is design as functional analysis, where problem requirements are fully available at the outset so that the traditional methods can be followed. The second is design as problem-solving, where complex, namely organizational, problems can be simplified to levels where they can satisfy minimal criteria for positivist solutions. The third is design as problem-setting, which views design as requiring the discovery and negotiation of unstated goals, implications, and criteria, following constructivist epistemologies. Finally, the fourth category is design as evolutionary learning, which sees design as the convergence of problem and solution in an emergent and constructivist process (Gasson, 2006). Typical values of the design dimension include compromising, resorting when necessary to non-scientific thinking, and deciding on the face of incomplete knowledge with the help of intuition and experience.

The dimension of engineering as a craft refers to the art of getting things done. It values the ability to change the world and overcome resistance and ambiguity (Sennett, 2008). It corresponds to the art of the *homo faber* and to the ability to roll up one's sleeves and get down to the nitty-gritty. In this dimension, the completed job, which stands before the world, leads to higher recognition.

Therefore, an epistemology of engineering can be seen as resulting from the aggregation of the four dimensions of engineering in a relationship of transdisciplinarity, with transdisciplinarity understood as the mutual interpenetration of the epistemologies of the various dimensions in the context of disturbances that shake up the corresponding systems of knowledge production (Figueiredo & Cunha, 2006; Gibbons et al., 1994). The basic sciences contribute to the relationship with their predominantly analytical and positivist epistemology. The human sciences carry their hermeneutical tradition, combined with some positivist influences. Design contributes as hinted above. Finally, the epistemology of the crafts is supported by the traditions of pragmatist philosophers and the work of Schön (1983) and his followers.

Looking across these four dimensions we may anticipate considerable conflicts in values, methodologies, and goals. As such, traversing this transdisciplinary space is not a simple synthesis, but rather a generative, emergent, and constructivist process. To engage future engineers we must let them experience the unique identity of engineering and the beauty of its kaleidoscopic combination of dimensions. We must let them realize that they can give full expression to their dreams and their talents by building their own configuration of commitments along these dimensions (more in one dimension, less in another) and by learning to collaborate and create collective value across them.

Carmen Schifellite—Using Epistemological Challenges to Teach About Modest Epistemologies

In this essay I want to talk about a strategy that I use to introduce students to complex epistemological issues (Schifellite, 2008). Epistemology is the study of how we know what we know. I begin this process in every class I teach, whether it is an undergraduate or graduate course, through a series of epistemological challenges that are aimed at getting students to think critically about the assumptions we have about how knowledge is produced and about its reliability and "truthfulness." At the same time, I want to get them to think about scientific "truth" in more pluralistic ways.

This strategy is important for engaging future engineers because engagement means more than recruitment. It means engaging students in critical thinking and in helping them to see the importance of critical engineering practice. The use of "critical" here is both crucial and socially significant. Many fields of engineering rely on science disciplines that have established cannons, or knowledge frameworks, that students are trained into and which students then use in their engineering practices. Increasingly, these cannons and the methods used to construct these cannons are coming into conflict with community-based research and demands that are being informed by competing challenges to these cannons. These challenges are being given more space and visibility as a result of increased accessibility of information. The communities that these students will eventually work for, and with, will become immersed in this pluralism of ideas. These communities will increasingly have large parts to play in the selection of knowledge, the development of objectives and the implementations of policy and design. The following paragraphs describe a sequence of exercises aimed at helping aspiring engineers take into account the desires, aims, and ideas of the communities they serve and develop the epistemological sophistication and flexibility to mediate this new pluralism.

One of the first exercises is to have students try and explain what money is and what it represents to us. They come up with many ideas that usually talk about power, the ability to buy things, status, and some eventually get to the point that they link money with labor. Ultimately, with guidance they come to the point where they can "see" that money is used to represent labor and as such is a social construction with powerful social impact.

A second exercise is to ask students to describe the desk or table that they are sitting at in class. They are pushed to come up with numerous kinds of descriptions and through this process to describe the same object at many different levels of reality. These range from design, aesthetics and function to social descriptions, like who made this desk and what does the use of this desk in a classroom tell us or imply about the social organization of this society. Either on their own or through prodding, some students also begin to describe the table at the atomic and subatomic levels. In this way, we begin to tease out the importance of both levels of analysis and standpoints in the initiation and focus of knowledge construction. This sets the stage later for arguing for the importance of using multidisciplinary and pluralistic approaches to policy development and problem solving.

I do this in conjunction with a third exercise in which I ask students if they know what causes most gastric ulcers. In 2005, Marshall and Warren were awarded the Nobel Prize in Physiology or Medicine for their work in discovering that a bacterium, H. Pylori, caused most gastric ulcers. Based on experience, typically between 0 and 5 students in 100 will know this. The exercise proceeds with telling the story of how it took these researchers twenty years to get the scientific community to accept their findings and we discuss the reasons why this was the case. Usually, in this discussion, there emerges the interest of the pharmaceutical companies for which the prescription drugs used to treat ulcers were most profitable. The conversation also includes the established medical specialties that also may not have wanted to hear that a simple and cheap treatment with a generic antibiotic could deal with most ulcers in a matter of weeks. This example introduces students to the idea of the ways in which standpoint and self-interest can influence what ultimately counts as fact and theory and ultimately what will count as reality. This exercise also usually involves a discussion of institutions like the Federal Drug Agency in the U.S. and its role as an arbiter of medical fact theory and treatment.

Once students begin to understand the significance of the reality of the social construction of knowledge and the importance of standpoint, self-interest, and power relations in the creation of knowledge, I can then move on to deal with the idea of modest epistemologies and pluralism in the sciences. Longino (1990, 2002) developed the notions of modest epistemologies and scientific pluralism to support the idea that while science knowledge is socially influenced, it can still be both useful and intelligible. To this end, she holds that we must begin to move away from the polarized and polarizing positions that either science produces truth or that it produces knowledge no different from an infinite number of purely personal or speculative exercises. Instead, she holds that we must move toward more modest aims in which science knowledge is seen as partial, plural, and provisional (Longino, 2002, p.207). To do this, one must not strive for "one superior and overarching explanation," but instead one must be able to tolerate and accept the coexistence of multiple competing paradigms. For her, this plurality is not a state that we need to resolve. Rather, we must understand that how we decide which of these to count as knowledge and to act upon "depends on the cognitive goals and particular cognitive resources of a given context" (Longino, 2002).

If engineers are going to successfully take into account the desires, aims, and ideas of the communities they serve it will require that they have the epistemological sophistication and flexibility to mediate this new pluralism. Ultimately, the acceptance of more socially-based and modest epistemological frameworks will decrease confrontation and antagonism between these groups, promote respectful and engaged dialogue between these camps and across disciplines and attract and engage future engineers who will be coming into the programs more sensitized to the urgency of these issues.

Alice Pawley and Julie Martin Trenor—Race, Class and Gender in the Context of Engaging Future Engineers

We have been asked to collaboratively introduce a set of communities that think differently about race, class, and gender, and how that affects how we think about engaging future engineers. In order to elucidate perspectives and practical experiences from researchers who work on these topics from different theoretical perspectives, we present the following conversation between Alice Pawley and Julie Martin Trenor, which is representative of many such conversations the two of us have had in face-to-face and virtual settings over the last several years.

Alice. When I think about my connection with this topic, I think about how changing what we think engineering is may change who engineers are. For example, from reading in feminist technology studies and women's history of technical education, I've learned how undergraduate programs in home economics in the United States were where scientifically minded women were historically pushed (Canel, Oldenziel, & Zachmann, 2000; Cowan, 1997; Frehill, 2004; Stage & Vincenti, 1997). But despite significant overlap of technical content, engineering remains a discipline of (white) men, and home economics of (white) women. This division must be understood through race/class/gender theory and history. So part of my goal in my teaching and research is to help engineering students problematize what they think engineering is (Pawley, 2009), and to help colleagues think more broadly about defining who engineers are, as the consequences of these definitions may be on the faces and lives we actually see in the undergraduate engineering classroom.

Julie. So it sounds like you are looking at the work that students do but which is argued to "not count" as engineering. I am also researching issues of race/class/gender, but from the point of view of students' academic and career decisions related to engineering using theories from educational psychology such as social cognitive career theory (Lent, 1994) and from sociology such as social capital theory (Lin, 2001). I have a fabulous opportunity to blend research into practice because I have just finished my term as president of Women in Engineering ProActive Network (WEPAN). As president, people regularly asked me, "How do we increase the number of women in engineering"? Smart, educated people are looking for a silver bullet, a simple answer—but there isn't one, nor for increasing participation of other underrepresented groups in engineering. That is why WEPAN is working on the issue from a *systems* perspective: our mission involves transforming culture in engineering education to promote the success of all women. But transforming culture is no easy task: it involves buy-in from stakeholders at all levels, including people reading this article.

Alice. It seems to me like we both connect with two different communities—to WEPAN's practitioner community and to women's studies researchers—to help us get new tools to engage students who have traditionally been systemically excluded from engineering.

Julie. That is right. My passion for these issues started when I taught at an urban university that was extremely diverse ethnically and socioeconomically. But the pedagogical techniques and assumptions I held about my students from my previous position were no longer valid. This experience really made me realize that a "one size fits all" mentality does not work in engaging future engineers, particularly "underrepresented" engineers as a group.

Alice. Here is a great example of our overlap. I once thought you could "model" women as a big collective group, and you did not need to look at all that complexity like "race" or "sexuality" or "class" or anything. Then I heard the same philosophical message you are describing from women's studies scholars, although they used a different vocabulary and grounding theories. This methodological problem of research implying that "one size fits all" is criticized by women's studies scholars through the idea of *intersectionality*: that you have to look at people from their positions at the intersection of many social dimensions. In engineering contexts, people would talk about findings they had about women, but they couldn't study race because "there weren't enough people of [some underrepresented]." This implies that white women have no race, that the experiences of all women within any ethnic group are somehow homogeneous, and it treats race as though it is a pesky and simple characteristic that we would like to "hold constant" in our statistical testing. Through reading women's studies research I learned race is a social construction, and understood the epistemological and methodological critiques against "holding race constant" so you could "vary" a different "dimension" (Harding, 1993; Jacobson, 1999; Slaton, 2010).

We should talk about one more thing. All of this interdisciplinary work around race class and gender is really difficult. Why do we bother?

Julie. In the United States, funding agencies and corporate partners for diversity organizations such as WEPAN are driven by the "business/economic" case. In other words, we need a larger, more diverse workforce in order to remain globally competitive; provide for America's national and economic security; and achieve the thought diversity necessary to create innovative products to reflect a changing domestic and global marketplace. Typically there is an interest in underrepresented students because of the recognition that they hold promise for increasing/diversifying domestic engineering talent pool. I completely agree. It is important for the U.S. to have the right talent to be a leader in STEM. But my primary motivation is not the "business case"; I am dedicated to equity of access and participation by all people in the educational and career opportunities that engineering can provide. In other words, because of *social justice*. There are whole groups of people who have historically been excluded from the individual economic prosperity that a STEM career can provide. We may have lost focus on helping underrepresented groups achieve individual prosperity by focusing on national prosperity.

Alice. My research is also driven by social justice. I use feminist research methods to hear the stories of those who continue to be overlooked in much underrepresentation research, especially the few women engineers of color who others are not studying because there are too few to make statistical claims, or so few they are identifiable (Lourde, 1984; Nielsen, 1990; Smith, 1987, 2005). These seem like poor reasons not to study underrepresentation of women of color.

Julie. But I find myself asking, have we had to diminish the social justice issue to get attention from funders to study race, class, and gender in engineering education? What have we sacrificed (or what people are not participating) if we make that bargain with funders to support our work?

Alice. Good question, perhaps to leave the reader with! ;-) A final note: This paper should give a snapshot of different perspectives on engaging future engineers. While we are just two perspectives, we bring with us a variety of experiences along different axes (along practical-theoretical, individual-national, science-social science, and economic-justice axes) which can show the reader our own sort of intersectionality.

Results and Discussion

The outcome of a multiple perspectives methodology is a meta-inquiring system, an open forum for critical and transformative dialogue (Linstone et al., 1981; Mitroff & Linstone, 1993). The process for creating a meta-inquiring system on engaging future engineers involved (1) traversing the multiple perspectives in this paper, (2) gathering central themes and variations across ways of framing "engaging," "future," and "engineers," and (3) mapping cross-cues and interactions among perspectives (Linstone et al., 1981).

Figure 2 represents a first approximation for a complex meta-inquiring system on engaging future engineers. As shown here, ideas within the eight essays are positioned as spanning a landscape of "engaging", "future", and "engineers". The circular arcs identify interactions of ideas across essays such as how decisions about what it means to be or think like an engineer interacts with choices about when and how to engage aspiring engineers, who considers engineering as a future career, and how we prepare future engineers for the complexities of engineering work. For example, the idea of "precursors to engineering thinking" spans all three areas of the map linking theories of engineering knowledge, theories of learning in the formative years of development, and constructivist approaches for engaging learners. The idea of "learning to influence affect" links the role of affective development in learning with feelings of belonging and aspirations to become an engineer. In a similar way, the idea of "socio-technical engineering education" links views on the nature of engineering to identity development. The idea of a "transdisciplinary epistemology" sits at the center of the map to emphasize the centrality of this idea in terms of epistemological development, learning to deal with pluralism, building value across paradigms, and being socially aware actors. Issues of intersectionality and institutional culture also sit at the

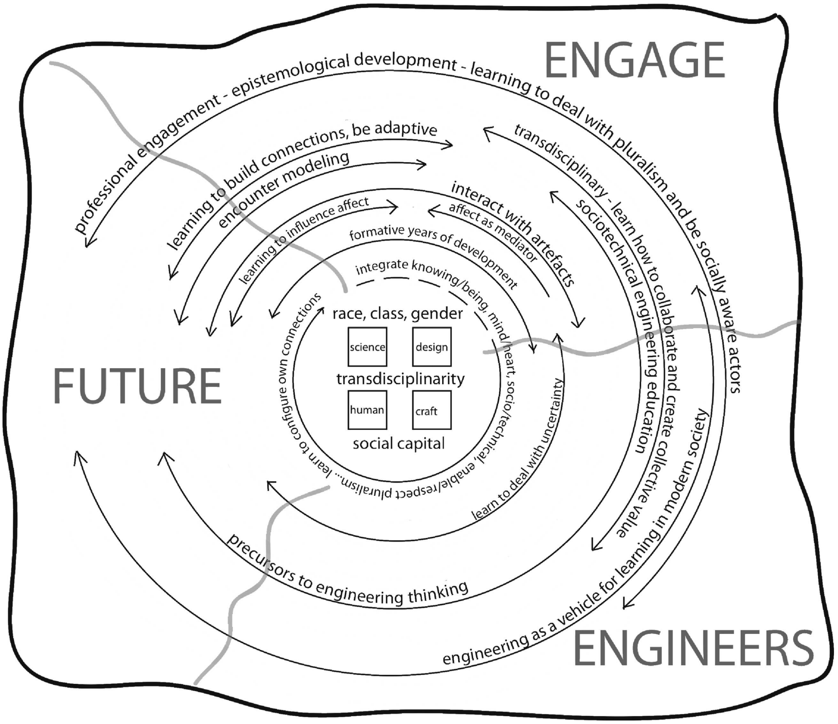

FIGURE 2. A meta-inquiring system on engaging future engineers.

center to emphasize associations between multiple social and cultural dimensions with being and becoming a future engineer.

As a meta-inquiring system, this new innovation landscape can be used to generate new lines of thought and questions of theoretical and practical significance (e.g., Atman et al., 2010). As shown in Figure 2, characteristics of "engaging" not only provide a way of talking about the quality of learning environments or persistence in engineering but also the interrelationships between engagement and cognitive, socio-technical, and affective attributes of deep learning and identity formation. This opens up new lines of scholarship and innovation such as (1) investigating how socio-technical engineering experiences influence a learner's understanding of and identification with engineering, (2) designing and assessing approaches for helping learners influence their own affect, (3) understanding relationships between engagement, deep learning, affective outcomes, and identity formation, (4) understanding the relationship between engagement and future learning or transfer, and (5) designing and assessing case-based materials of heterogeneous engineering projects to develop capacities to see and notice socio-technical aspects of engineering work and shape successful engineering projects.

Similarly, characteristics of "future" in Figure 2 illustrate a broad timeline for conceptualizing engineering thinking and the process of aspiring to be a future engineer. This timeline links engineering thinking from the formative years of development into professional practice in terms of learning how to deal with situations of uncertainty, have agency for self-initiated discovery learning, and develop lifelong skills for making connections and influencing affect in different contexts. It also reframes the idea of engineering as a vehicle for learning other content (e.g., mathematics and science) to a unique way of knowing that can be a vehicle for learning in contemporary society. This opens up new lines of scholarship and innovation such as (1) conceptualizing engineering thinking as a vehicle for learning in a contemporary society, (2) characterizing precursors of engineering thinking from early childhood into professional practice, (3) creating developmentally and pedagogically appropriate ways to facilitate early engineering thinking that can successfully be integrated within formal and informal P-12 contexts, (4) investigating influences on engineering identity formation in the early years of childhood development, and (5) developing methodologies for investigating the longitudinal nature of engineering thinking and identity formation.

Figure 2 also illustrates ways to problematize the nature of engineering knowing, the culture of engineering education programs, and the ways we think about aspiring engineers as living at the intersection of multiple social dimensions. Moving beyond a "one-size-fits-all" view suggests that there are multiple constructions about what counts as engineering and therefore multiple pathways into engineering and variations around what it means to be an engineer. This view is likely to conflict with our current approach to engineering education as well as the ways we assess learning and conceptualize epistemological development in engineering. This opens up new lines of scholarship and innovation such as (1) identifying ways to help students construct an understanding of engineering that relates to how they see themselves as future engineers, (2) developing ways to prepare future engineers to be sensitive to and aware of the complexities of engineering work that require flexibility in dealing with the ways truth is partial, pluralistic, and provisional, (3) investigating how current engineering education practices map to a transdisciplinary space of engineering epistemology and support epistemological development across complex science-human-design-craft dimensions, (5) conceptualizing an epistemology of engineering through a lens of social justice or race, class, and gender, and (6) exploring complex system and intersectionality methodologies for understanding engineering education cultures or understanding the experiences of learners from their positions at the intersection of many social dimensions.

This article also illustrates a process and set of underlying principles for taking a multiple perspectives methodology that may be used to understand other "wicked" or intractable engineering education problems such as the design of effective engineering instructional development and the uptake of educational innovations (Felder, Brent, & Prince, 2011). The underlying principles of this process include recognizing the interrelatedness and inseparability of perspectives within a complex inquiring system, challenging assumptions and addressing the limitations of single-paradigm approaches, and enabling unbounded systems thinking and transdisciplinary transformation (Linstone et al., 1981; Mitroff & Linstone, 1993).

The process of using a multiple perspectives methodology includes encouraging divergent cross-disciplinary thinking, making visible aspects of a phenomenon, such as "engaging future engineers," that may not be included or emphasized in current frameworks, and creating conceptual dilemmas that challenge prior perspectives and open up pathways to transformation and innovation. There are also principles for making decisions about ways of experiencing, selecting, and communicating multiple perspectives. One principle is to design for immersion and iteration. As Linstone et al. (1981) note, the goal is to create a "slow-cooker" and not a "pressure-cooker" experience. Key principles for selecting perspectives consist of designing for inclusiveness and balance while designing for conflict. Including an interparadigmatic mix facilitates bringing assumptions to the surface for open dialogue and sets in play a process for making connections, experiencing disorienting dilemmas, and transformative thinking. The outcome of a multiple perspectives methodology is a meta-inquiring system, an open forum for critical and transformative dialogue (Linstone et al., 1981; Mitroff & Linstone, 1993). It is not a static endpoint but a dynamic space that supports cycles of revisiting underlying assumptions and transdisciplinary immersion over time (Linstone et al., 1981).

CONCLUDING REMARKS

A significant body of research suggests that despite extensive long-term investments in engaging future engineers, the overall impact has been less than intended. We began with an argument that a lack of intended progress is a consequence of ineffective problem formulation that has limited the space for imagining effective engineering education innovations. A multiple perspectives methodology was used to gain traction on the "wicked" problem of "engaging future engineers" and create a meta-inquiring system that makes visible high impact engineering education innovations that embraces the complexities of what it means to be and become an engineer, experience an engineering education, and consider engineering as a future goal.

This new innovation landscape communicates two central themes for engineering education scholarship and innovation. First, it emphasizes the entwinement of learning and engaging, mind and heart, social and technical, knowing and being, being a professional engineer and being a social actor, and multiple dimensions of science-human-design-craft and race-class-gender. Here, "entwinement" (dall'Alba, 2009) is a deliberate choice of words that emphasizes how these ideas are holistically connected, that each is in service to the other and of equal importance. Second, it illustrates how conceptualizations of "engineering" may have transformative power for imagining what it means to engage aspiring engineers and be an engineering professional.

Because the representation in Figure 2 provides a first approximation of issues regarding engaging future engineers, it represents only part of a larger complex system. As such, the strategies used in this paper may serve as tools for continual dialogue. With this in mind, we encourage readers to construct their own maps, discuss them with colleagues, and debate what is emphasized and the associated consequences for engaging future engineers. Table A1 in the Appendix provides a list of discourse communities (e.g., conferences and journals) for readers to embark on their own "multiple perspective" explorations and engage in an open process of examination, respectful negotiation of ideas, and cross-disciplinary discovery.

Finally, this paper illustrates by example the process, underlying principles, and value of taking a multiple perspectives methodology to challenge prior assumptions and configure a meta-inquiring system that reveals new areas of scholarship and innovation. As such, this methodology may have broader significance as a strategy for understanding other "wicked" or intractable engineering education problems including those described in this volume: (1) acquiring engineering expertise (Litzinger et al., 2011), (2) diversity, retention and career decision making (Borrego & Bernhard, 2011), (3) effective engineering instructional development and the uptake of educational innovations (Adams & Felder, 2008; Felder et al., 2011), and (4) a science of how people learn engineering and identify as (aspiring) engineers (Johri & Olds, 2011).

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APPENDIX

TABLE A1
Author Discourse Communities Associated with Engaging Future Engineers

Author	Community Journals and Conferences
Robin Adams	• *Co-Design* • *Design Studies* • *Journal of Engineering Education* • *International Journal of Engineering Education* • American Educational Research Association Annual Meeting • American Society for Engineering Education Annual Conference • Design Thinking Research Symposium • Frontiers in Education Conference • International Conference of the Learning Sciences • International Conference on Engineering Design • Research in Engineering Education Symposium
Antonio Dias de Figueiredo	• *Engineering Studies* • *Philosophy & Technology* • *Techné: Research in Philosophy and Technology* • *Technology and Culture* • *Technology and Society Magazine* • Forum on Philosophy, Engineering & Technology (fPET), an outgrowth of the 2007 (TUDelft, Delft) and 2008 (Royal Academy of Engineering, London) workshops on Philosophy and Engineering (WPE) • International Conference on Engineering Education International Symposium on Technology and Society (ISTAS) sponsored by IEEE
Demetra Evangelou	• *Early Child Development and Care* • *Early Childhood Research and Practice* • American Society for Engineering Education Annual Conference • Frontiers in Education Conference • Research in Engineering Education Symposium
Lynn D. English	• *Australasian Journal of Engineering Education* • *Contemporary Educational Psychology* • *Educational Studies in Mathematics* • *Journal for Research in Mathematics Teacher Education*

TABLE A1
Continued

Author	Community Journals and Conferences
	• *Mathematical Cognition* • *Mathematics Education Research Journal* • *Mediterranean Journal for Research in Mathematics Education* • *School Science and Mathematics* • *The International Journal on Mathematics Education* • *Teaching Children Mathematics* • *Thinking and Reasoning* • European Research in Mathematics Education • International Conference on the Teaching of Mathematical Modeling and its Applications • International Congress on Mathematical Education • International Group for the Psychology of Mathematics Education • International Symposium on Research in Engineering Education • Mathematics Education Research Group of Australia • National Conference of Teachers of Mathematics
Nicholas Mousoulides	• *European Journal of Engineering Education* • *International Journal of Technology in Mathematics Education* • *International Reviews in Mathematics Education* • *Journal of Engineering Education* • *Journal of Research in Mathematics Education* • *Mathematical Thinking and Learning* • *The Philosophy of Mathematics Education Journal* • ASEE Global Colloquium in Engineering Education • Conference of the European society for Research in Mathematics Education • International Conference for the Psychology of Mathematics Education • International Conference on Engineering Education and Research • International Conference on the Teaching of Mathematical Modeling and Applications • International Conference on Technology in Mathematics Teaching • Research in Engineering Education Symposium

TABLE A1
Continued

Author	Community Journals and Conferences
Alice Pawley	• *Engineering Studies* • *Journal of Engineering Education* • *NWSA Journal* • American Society for Engineering Education Annual Conference • Engineering, Social Justice and Peace Conference • Frontiers in Education Conference • Inclusive Science: Articulating Theory, Practice and Action • National Women's Studies Association National Conference • Professional and Organizational Development Network in Higher Education National Conference • Race and Pedagogy Conference • Research in Engineering Education Symposium • Society for the Social Studies of Science Annual Conference • Society of Women Engineers Conference
Carmen Schifellite	• *Professing Education* • Engineering, Social Justice and Peace Network Conference • International Society for the Study of the History, Philosophy and Social Studies of Biology • International Technology, Education and Development Conference
Reed Stevens	• *General Anthropology.* • *Interactive Multimedia Journal of Computer-Enhanced Learning* • *Journal of Engineering Education* • *Journal of Museum Education* • *Journal of the Learning Sciences* • *Mind, Culture, & Activity* • *Review of Educational Research* • *Science Education* • *The Journal of Computer Science Education*

Table A1
Continued

Author	Community Journals and Conferences
	• American Educational Research Association Annual Meeting • American Society for Engineering Education Annual Meeting • Computer Supported Collaborative Learning Conference • Conference of the Cognitive Science Society • Ethnography in Education Forum • European Association for Research on Learning and Instruction • International Conference of the Learning Sciences • Society for Social Studies of Science (4S) • Society of Applied Anthropology • The International Society for Cultural Research & Activity Theory Conference
Marilla Svinicki	• *Academic Exchange Quarterly* • *College Teaching* • *Contemporary Psychology* • *Educational and Psychological Measurement* • *Innovative Higher Education* • *Journal of Educational Research* • *Journal of Experimental Education* • *Journal of Graduate Teaching Assistant Development* • *Learning and Individual Differences* • *New Directions for Teaching and Learning* • *The Journal of the Scholarship of Learning and Teaching* • American Educational Research Association Annual Meeting • American Psychological Association Annual Meeting • International Conference on Improving University Learning and Teaching • Professional and Organizational Development Network in Higher Education • The Teaching Professor Conference

TABLE A1
Continued

Author	Community Journals and Conferences
Julie Martin Trenor	• *Journal of Engineering Education* • *Journal of STEM Education* • *Advances in Engineering Education* • *Journal of Women and Minorities in Science and Engineering* • American Educational Research Association • American Psychological Association • American Society for Engineering Education Annual Conference • Conference on Latino Education and Integration • Frontiers in Education Conference • Research in Engineering Education Symposium • WEPAN National Conference
Denise Wilson	• *Journal of Engineering Education* • *International Journal of Engineering Education* • American Society for Engineering Education Annual Conference • Frontiers in Education Conference • National Environmental Public Health Association Conference • Special Interest Group of the Computer Science Education division