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Keywords

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The Humanistic Side of Engineering: Considering Social Science and Humanities Dimensions of Engineering in Education and Research

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Abstract

Mathematics and science knowledge/skills are most commonly associated with engineering's pre-requisite knowledge. Our goals in this paper are to argue for a more systematic inclusion of social science and humanities knowledge in the introduction of engineering to K-12 students. As part of this argument, we present a construct for framing the humanistic side of engineering with illustrative examples of what appealing to the humanistic side of engineering can look like in a classroom setting, and opportunities for research that examines the dynamics that the humanistic side of engineering introduces into engineering learning and teaching. The illustrative examples are drawn from interactions among student-teams from elementary classrooms engaged in engineering activities that appeal to the humanistic side of engineering. Referencing these examples as well as other established engineering education programs, we will discuss opportunities for research in the education of K-16 students. These opportunities span understanding how students' attitudes, beliefs, and perceptions shift, particularly among traditionally underrepresented populations, to how students' engineering knowledge and practices develop in the context of a humanistic approach to engineering.

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Introduction

Although we maintain that engineers apply mathematics and science knowledge in their work and that engineering can provide motivating contexts to learn mathematics or science, we posit that engineers navigate a wealth of social science and humanities knowledge and skills in the engineering and design of solutions. A common dictionary definition of engineering—"the application of science and mathematics by which the properties of matter and sources of energy in nature are made useful to people" (Engineering, 2012)—emphasizes the application of science and mathematics but places a qualifier on that application: that the end product be "made useful to people." The "people" part of the definition, which we will refer to as the humanistic side of engineering, is what we highlight in this paper. Drawing attention to the humanistic

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side of engineering is not without precedent. ABET criteria (2012), innovations in engineering curriculum and programs (Coyle, Jamieson, & Oakes, 2006; Fisher & Mahajan, 2003; Fisher & Mahajan, 2010; Olds & Miller, 2004), and industry (Black, 1994; Spinks, Silburn, & Birchall, 2006) are calling for a more holistic approach to engineering education as employers note the lack of communication skills among entry level engineers. The innovations in this area have primarily focused on change at the college level of engineering education leaving few clear examples of how a humanistic approach might look at the K-12 level. We posit there is also a lack of systematic research investigating exactly how and why such an appeal to the humanistic side of engineering can positively influence both the skills and abilities of students and the recruitment and retention of students into engineering from elementary school through college. In this paper, we propose a construct that illustrates how social science and humanities knowledge and skills are applied in the pursuit of engineering *for* people as one engineers *with* people. In proposing this construct, we call for educators and education researchers to consider the humanistic side of engineering as a distinctly important, but not separate, part of engineering that needs to be systematically researched as such ideas are adopted across programs and curriculum.

Our goals in this paper are to present a construct for the humanistic side of engineering to: 1. Illustrate what appealing to the social science and humanities dimensions of engineering can look like in a classroom setting; and, 2. Illuminate research opportunities for examining the dynamics that such an appeal has on engineering learning and teaching. The paper first describes the theoretical framework that supports the construct, namely the epistemological and philosophical roots of the integration of social science and humanities with engineering. We then present the description of the construct for the humanistic side of engineering that centers on the people involved in engineering. To illustrate what this may look like in the classroom, we provide data of elementary students engaged in classroom engineering activities appealing to the humanistic side of engineering. The final discussion of opportunities for research in this area references these examples as well as other established engineering education interventions.

The Humanistic Side of Engineering

The term "humanistic engineering" has been used to describe the integration of the humanities and social science disciplines with engineering (Fisher & Mahajan, 2003; Fisher & Mahajan, 2010; Wulf, 2004). Applying such knowledge or skills to a real-world problem is also sometimes referred to as "soft" (Pulko & Parikh, 2003), which can conjure up a pejorative connotation. Referring to these skills and knowledge as soft is in contrast to the "hard" knowledge that exemplifies the technical, more exacting aspects of engineering often represented in engineering's mathematical and scientific roots. However, we do not believe the connotation that "soft" is easier and "hard" is harder is necessarily true in engineering. Berliner (2002) described the dichotomy of the "hard" and "soft" sciences and noted that the "soft" sciences are often much more difficult in the practice of science because they can be "squishy, unreliable, and imprecise to rely on as a basis for practice" (Berliner, 2002, p. 18) making the job of the social scientist that much more difficult as they try and control for the uncontrollable. The laws that guide the "hard" sciences (e.g., physics, chemistry, biology, mathematics) rarely change and provide engineers reliable, hardened frameworks and constraints within which to design. The constraints imposed by people and societies are ambiguous and shifting posing serious and challenging judgment calls and empathetic decisions (Strobel et al., 2011) for engineers as they work toward the best solution. Thus, to avoid the potential controversy that can arise in referring to the knowledge and skills of engineering as "hard" or "soft," we use the term humanistic to refer to what some call the "soft" skills of engineering and are of the view that the humanistic aspects of engineering make engineering quite difficult in practice. We describe six humanistic disciplines and their relevance to the practice of engineering in the following sections. These are not the only social science and humanities disciplines pertinent to engineering. We selected a subset of disciplines to highlight the ways in which such disciplines are applied in engineering. The following disciplines were selected out of convenience owing to the more robust nature of literature tying them to engineering.

Psychology

The design of human tasks, human-operated equipment, and human-machine systems benefits from the application of knowledge of how people attend, perceive, think, remember, decide, act, and behave. An appreciation of the nature of human limitations and the systematic study of human performance informs the design of solutions that optimize the efficiency of use. Principles from psychology can also inform design specifications to increase the appeal of designed artifacts (Fitts, 1958; Lidwell, Holden, & Butler, 2010; Wickens & Kramer, 1985).

Sociology

Understanding the sociology associated with how groups of people perform socially distributed tasks informs the engineer in the design of systems and artifacts that improve the performance or efficiency of the tasks. Recognition of sociology as the dynamics of how different groups of people work together on the design and delivery of complex systems designs informs collaborative and teamwork aspects of engineering work. Furthermore, engineers, as ethical practitioners, must consider the social implications and sustainability of their products (Akay, 2008; Bentley et al., 1992; Bijker, Hughes, & Pinch, 1987; Law, 1987; Law & Callon, 1988).

Communications

The ability to communicate ideas both orally and through writing is critical to successful engineering. The design and development of solutions requires various forms of communication, using multiple representations, with the end-users, suppliers, manufacturers, and an interdisciplinary team. Accreditation boards call for the development of communication and teamwork skills in higher education as employers emphasize the need for these skills for success in the workplace (Ford & Riley, 2003; Smith, 1995; Woods, Felder, Rugarcia, & Stice, 2000).

Law

Engineered solutions have to adhere to laws or standards set forth by local, national, and international government bodies. Engineers need to be aware of these laws and standards and design within the constraints they impose. Additionally, legal contracts dictate the chain of responsibility in complex projects and can greatly impact the economics of an engineering project. Understanding patent law can also dictate what an engineer can or cannot design into their next product. There are a great number of law or legal practices that must be followed in the design and development of many devices and systems that are in place to keep people safe and hold offending parties culpable (Samuelson & Scotchmer, 2001; Sweet & Schneier, 2008).

Economics

As engineers design, they select and manage resources (materials, labor, time, manufacturing, support, etc.) to optimize their design across a number of constraints. An "awareness of the finite limits of earth's resources has added a pressing dimension to engineering… The focus on scarce resources welds engineering to economics" (Riggs, Bedworth, & Randhawa, 1996, p. 4). Managing design within the constraint of cost is often much more complex than simply selecting the least expensive option. Economics factor into the selection of the materials, which may include their longevity or long run versus short run cost; the manufacturing of solutions, which may include capital investment in specialized equipment; the maintenance of solutions, which may increase with the selection of cheaper, lower-quality materials; and numerous other factors from the various stakeholders. Engineering economics is a field of study within many engineering disciplines and handbooks are created such that engineers can quickly refer to estimated costs associated with various selections they make. The ability to recognize and deal with the economics within specific engineering disciplines are formally tested in pursuit of becoming a licensed professional engineer (PE) (Boehm, 1984; Fish, 1915; Riggs et al., 1996; Samuelson & Scotchmer, 2001).

Philosophy/Ethics

Philosophy within engineering focuses "on ways in which technology shapes individual lives and a range of social institutions" (Kroes, Vermaas, Light, & Moore, 2008, p. 2). From this perspective, engineers need to consider the impacts, both intended and unintended, of the solutions they create. The consideration of these impacts introduces a moral or ethical dimension for engineers, either as decision-makers or subordinates to the decision-makers, who are charged with making choices of right vs. wrong as they encounter risks associated with design decisions. Laws and standards can help regulate such ethical decisions, however, especially in cases dealing with emerging technologies (i.e., genetics or artificial intelligence) the laws lag behind technological innovation leaving serious ethical decisions to be made by the developers. (Ihde, 2008; Kroes et al., 2008; Pinkus, Shuman, Hummon, & Wolfe, 1997).

Framework for Humanistic Side of Engineering

Each of these disciplines has spawned sub-disciplines or college programs and courses such as Engineering Psychology (or Human Factors), Engineering Ethics, Patent Law, etc. that could be studied in depth. Although it is possible to study or teach these six disciplines independently, we suggest that educators consider a broader view that aims to incorporate the big ideas from these disciplines as appropriate. For example, how can students use ideas from these disciplines to inform their decision-making?

Taking the view that engineering in practice includes the application of social science and humanities knowledge, we look to further build on Law's (1987) heterogeneous/socio-technical and Grasso and Burkins' (2009) holistic engineering theoretical frameworks for engineering, where technical and social aspects of engineering go hand-in-hand. The framework we propose can be applied to thinking about engineering more generally; however, in response to Stevens' (c.f. Adams et al., 2011) proposition to consider a socio-technical (or humanistic) approach to engineering education, we have targeted the construct for application in the development and research of K-16 engineering education initiatives.

The framework consists of two perspectives through which to view the application of humanistic skills and knowledge in engineering. Referring back to the special attention we paid to the people part of the definition of engineering, we invite you to consider that there are two lenses through which to view the people involved in the development of solutions. There are the people *for* whom engineers are solving a problem and the people *with* whom they are solving the problem. Engineering *for* people requires that engineers consider the needs of the people who will use or in some way be impacted by the engineered solution. Engineering *with* people highlights the idea that engineers rarely work in isolation and work with people of different backgrounds and expertise, and with different goals at stake in the development of the solution. Furthermore, whether thinking about whom the engineer is engineering *for* or *with*, there exists a spectrum of impact, which represents the number or diversity of people involved, along which engineering projects may fall. The graphic below illustrates the two lenses through which to view people and the spectrum of the size or population of the people affected.

All the six disciplines we listed in Table 1 and other disciplines may be applied in thinking about designing *for* or *with* people. The lenses we propose to view the people associated with engineering projects focus attention to creating contexts where students are aware of the people they engineer *for* or *with* where they can then apply the entire range of knowledge and skills from all relevant disciplines of knowledge.

Engineering for People

One group of people associated with engineering projects are those for whom engineers engineer *for*. Scholars of engineering philosophy and epistemology highlight the existence and evolution the social contexts within engineering (Bucciarelli, 1994; Norman, 2002; Vincenti, 1990) and that engineers' work primarily addresses human needs or problems. Within this social context there are constraints and requirements dictated by the various members of the society at varying scales of impact. We will start at the extreme right of Figure 1 and consider the larger social impact engineers may have on the world. Engineers push the boundaries of imposed constraints and requirements to optimize their solutions, which when directed on projects that have far-reaching impacts on people, societies, and the world can lead to transformative social change. Law & Callon (1988) suggest that "engineers are not just people who sit in drawing offices and design machines; they are also, willy-nilly, social activists who design societies or social institutions to fit those machines (p. 284)." While Law & Callon's term "willy-nilly" evokes a seemingly haphazard approach to affecting social change, which may be true at times, there are also very deliberate and conscious decisions made by designers and engineers. Engineered innovations have been paramount to the evolution of human society. Take, for example, the hydraulic engineering feats of the Urban revolution (roughly 5,000 years ago) that intensified agriculture enabling the creation of centralized civilizations—transforming how humans interacted and evolved as a social species. More recently developments made possible by Internet technologies, such as Twitter©, have provided means by which oppressed people can organize to protest their governments (Landler & Stelter, 2009). The engineers and designers behind these developments may not have created their technologies specifically for such purposes, but, as in Twitter's case, they were aware that the real-time connecting of people and information was a breakthrough in the way people would share and receive information (Twitter, 2012). Numerous other engineered innovations (e.g., electrical grids, the telephone, the automobile, the Internet, human genome sequencing, etc.) have had tremendous societal implications that engineers in one way or another addressed in their work.

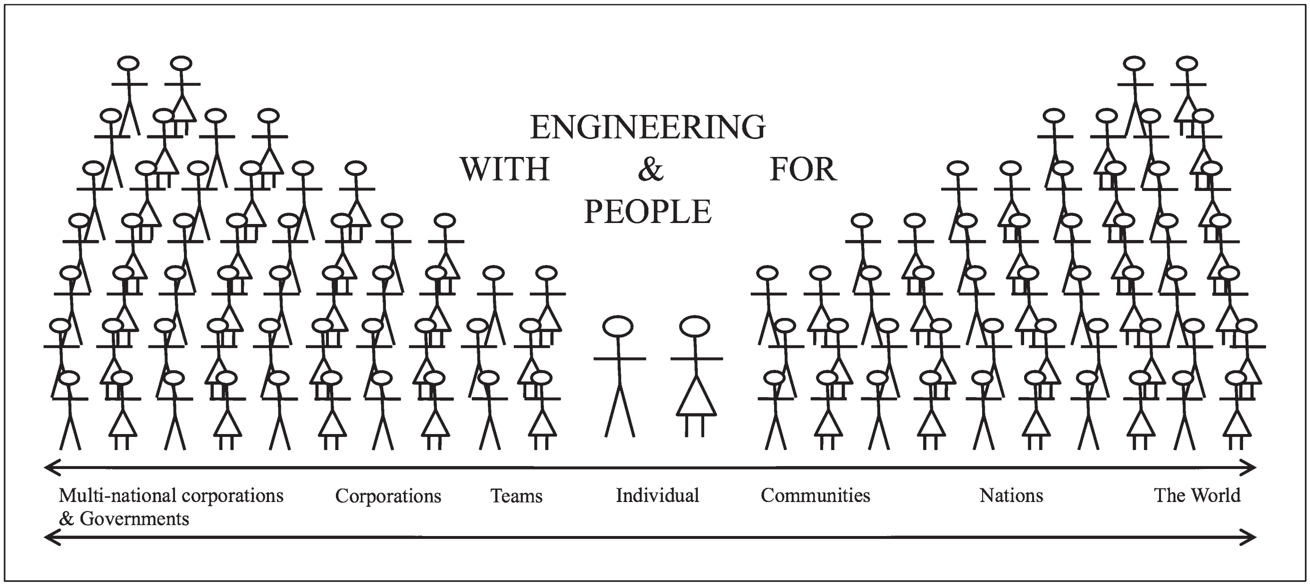

Figure 1. Engineering with and for people construct diagram.

Shifting to the other end of the spectrum from a macro-level perspective to a more micro-level perspective, engineers create solutions for the individual user. This can vary from designing a one-of-a-kind device for an individual or something for a particular target population of people. Fields of study such as human or user-centered design and human-computer interaction have emerged to address, with much more focus, the specifics of how to design for human use. There are the more straightforward physiological constraints to consider when designing for people, but as Norman (2002) describes the psychology of people should be much of what designers consider in their work. Norman describes the consideration of human psychology as ranging from designing to avoid or compensate for common types and sources of "human error," to address knowledge embedded in individuals and the world and how they emerge both consciously and subconsciously. From this lens, the design of the things around us become better when engineers or designers can take the perspective of their users and learn about how they think and interact with the world around them.

Descriptions of the epistemology of engineering often include the reference to the work of the engineer as serving humans needs (Bucciarelli, 1994; Figueiredo, 2008; Vincenti, 1990), which can refer to both engineering for social change or engineering for humans at the mezzo- or micro-level. Often the goals of an engineered artifact relate to making life easier or more enjoyable for people in some way. In order to design in service of human-centered goals, engineers must be aware of human phenomena and apply knowledge of such phenomena (i.e., humanities and social sciences). However, applying this kind of knowledge is rarely systematically integrated into engineering curricula and is often treated as a tertiary body of knowledge and skills for the engineer in training.

Engineering with People

Solving engineering problems requires knowledge from a variety of domains and benefits from teams of individuals bringing multiple perspectives. Engineers, working in teams, collaborate to optimize their solution by integrating team members' ideas and expertise (Stempfle & Badke-Schaub, 2002) and making decisions informed by those diverse viewpoints (Bucciarelli, 1994). Engineering requires negotiating between team members' differing viewpoints regarding the tradeoffs that emerge between design features and constraints. In collaborative teams, individuals also have to negotiate what it means to design as people orient to the practice of design differently. This all requires some sort of social negotiation dependent on interpersonal, communication, and teamwork skills. This sort of social construction of engineered artifacts cannot be avoided. Better solutions arise when diverse perspectives contribute to the creation of artifacts. Those who study collaboration and group work of engineering teams highlight how important interpersonal and social dynamics are to the process (Hacker & Kleiner, 1996; Hammond, Koubek, & Harvey, 2001; Stempfle & Badke-Schaub, 2002) and that the form of communication (in-person or virtually) within a design group matters (Harvey & Koubek, 1998). Stempfle and Badke-Schaub (2002) found that approximately 1/3 of the communication within a group designing collaboratively was aimed at structuring the group's process. Research comparing professional engineers to engineering students found that practiced professionals organized themselves as a group much more effectively than did the students (Smith & Leong, 1998). Professional engineers also communicated with each other throughout the process to "stay on the same page," understand their failures, resolve disagreements and challenges, and reflect on their process (Hacker & Kleiner, 1996; Harvey & Koubek, 1998; Smith & Leong, 1998; Stempfle & Badke-Schaub, 2002). All of which takes some social skill.

We make this point that engineering, not unlike many professions, is a highly social endeavor because of stereotypes that engineering is not for "people people" (Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). A stereotype that is often reinforced for underclassmen completing their pre-requisite courses sitting in large science lecture halls and studying for Calculus tests they will take as individuals. This is what some refer to as the "weeding out process" (Sheppard et al., 2004). We believe that not only does it "weed" out those with weaker mathematics and science knowledge or ability (as measured by the lecture hall exams), but that it also weeds out the "people people" who may have been excited about working with people to solve problems that contribute to society. By de-emphasizing the social, collaborative nature of engineering, engineering education is limiting the people that consider engineering and doing a disservice to those who persist by not sufficiently preparing them for the kind of work engineers actually engage in (Smith & Leong, 1998). We agree with those pushing for cooperative learning pedagogies (Smith, 1995) in the engineering curriculum, and would push for it to be extended earlier in the curriculum and become a part of the engineering education ethos.

The Humanistic Side of Engineering in the Classroom

We will now present a few examples of what the humanistic side of engineering can look like in the elementary classroom. The following examples were not from lessons or activities that were specifically designed to apply the construct we have proposed. What these examples have in common is that the engineering projects the students are engaged in were situated in richly developed social contexts. As such, they provide opportunities for the humanistic contexts to arise organically, which we argue lead to teaching and learning moments where students come to identify and understand the diverse sorts of knowledge and skills one draws on as they engineer solutions.

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Methodological Design and Methods

The broader design of the research, which the data herein come from, focuses on the rich interactions between students, teachers, and classroom engineering activities. The goal of the research is to examine the dynamic interplay between these three variables to uncover phenomena that promote authentic engagement in engineering practices. The research team collected a rich set of videotaped classroom observations and associated student and teacher-generated classroom artifacts (e.g., worksheets, projects, board work, etc.). The team followed an interaction analysis approach (Jordan & Henderson, 1995) in analyzing the data. Interaction analysis' roots lie in ethnography and focus on the investigation of "human activities such as talk, nonverbal interaction, and the use of artifacts and technologies" (Jordan & Henderson, 1995, p. 39). This method allows for the research team to go beyond the analysis of discourse (talk) and factor in two critical aspects of engagement in engineering practice—nonverbal interactions and the use of artifacts. Jordan and Henderson describe the analysis process as one where individuals or small teams within the larger research team identify data—video clips—that highlights some phenomenon they are interested in examining further and then present those data to the entire team, which generally takes the form of an interdisciplinary group of researchers with diverse perspectives. For example, some researchers noted the students' epistemological framing (Scherr & Hammer, 2009) of the engineering activities, others highlighted the nature of the engineering practices in which the students engaged, and others discussed the inter-disciplinary nature of the work (i.e., literacy, science, mathematics). Analyzing the video within a large (ten or more researchers), diverse (engineers, science educators, literacy experts, engineering educators) group reduces the idiosyncratic bias of the individual researcher (Jordan & Henderson, 1995). From these group analysis meetings, the authors of this paper organized the group feedback related to the topic of this paper (humanistic side of engineering) into a coherent story. The coherent story was then presented to the group for further review. The feedback helped shape the final analysis and interpretations presented below.

The data that follows comes from three different public school elementary classrooms from three Massachusetts communities—one rural, one urban, and one suburban. The first example presented comes from an urban school participating in a curriculum designed to have students solve problems for their school community. The remaining examples come from schools participating in the Integrating Engineering and Literacy project. The data collection for all the examples included videotaped classroom observations that included a mix of classroom-wide stationary cameras, stationary student group cameras focused on a specific pair of students, and a roving camera a researcher used to ask questions as they moved from group to group. In addition to the videotaped observations, the team scanned or photographed student-generated artifacts. Research team members with cameras were present in the classrooms throughout the sessions when the engineering activities took place, which ranged from 3–8 sessions. All the names in the examples below are pseudonyms.

Engineering for the School Community

Engineering for global change (far right of Figure 1), where final solutions actually affect the world, might occur as unrealistic for an elementary classroom. However, a school community of 200–500 students, teachers, and staff can provide an authentic opportunity for young students to engineer solutions that make a difference for a large community of people and effect social change. The following example comes from a fifth-grade classroom engaged in an engineering challenge modeled after the Purdue Engineering Projects In Community Service (EPICS) program (Coyle et al., 2006)—a program that matches engineering undergraduates with community partners to identify and solve locally situated problems. In the case of the fifth-grade students whose dialogue is presented below, the community is the school. In this engineering project, the students are asked to brainstorm problems that the school community faces that they might be able to solve as "engineers." One group of students is describing the problem they have selected to pursue to Mr. Jones, their teacher, in this excerpt.

> Stephen: What I'm trying to say is that I see kids by themselves. Not in line, but like, by themselves going into other people's lines. And making a huge, like collision. That's why I'm like…
> Mr. Jones: So it seems like… I'm just gonna take it one step back. So the problems are that there are kids going in other lines. There's people going up… What are the other problems?
> Stephen: The big problem is getting lost.
> Mr. Jones: Getting lost, where.
> Stephen: Well, I've gotten… because one time… (Bella's gestures agreement) there was these … all the classes were coming down at the same time… and my class was going up I don't know why, but…
> Mr. Jones: You got run over? You got bumped around?
> Stephen: yeah… and also accidents. I heard someone… I think my friend was… there was a big thing. She fell down on the stairs and she got run over by a big crowd.
> Bella: Oh I heard that.
> Mr. Jones: Wow!
> Stephen: She broke her arm.
> Mr. Jones: That happened here?
> Stephen: Yeah.
> Mr. Jones: So there's um collisions.

> Bella: Um, and when kids are coming down the stairs … if it's like a train, they also follow the other classroom. They're like "where am I going?" and they can't find their…
> Mr. Jones: Okay, so here's the thing… figure out what are our problems. So you're thinking that a sign is going to remedy all these situations instead of … it's gonna fix all of them.
> Stephen: Of course of course… I know that people aren't going to want to help, because there's people who are like, "let's not follow these (inaud) it's stupid." So this is why we're making a prototype or test thing, so if something goes wrong, We're gonna try and make it stand out more. Like make it big. We'll cover the whole railings.

Stephen and Bella are framing the problem using their personal experiences as members of the school community—"people aren't going to want to help" initially. We argue that this is a form of sociological knowledge they have developed through their participation in the school community. However, Stephen, Bella, and their teacher are probably not thinking of the knowledge they are applying in these terms. Stephen quickly realizes that the unpredictable response by students necessitates that they—"make a prototype or test thing"—to test their idea and iterate on a design to achieve their goal of making the way people travel up and down the stairs more efficient. The distinction we want to draw attention to relates to how the students are able to make choices, informed by their own sociological understanding of the school community, as they frame the problem and contemplate possible solutions; instead of a teacher or curriculum writer framing the problem within some fictional setting for them. Furthermore, Stephen and Bella are able to predict possible outcomes, even without further research, of their design ideas—"there's people who are like, let's not follow these … it's stupid"—as they can more easily take the perspective of potential users as they are themselves such users. We see that in this example Stephen and Bella might have been coached to conduct further research to better define or frame their problem. What might Stephen and Bella have learned if they collected data, as ethnographers (a method often employed by sociologists), by observing the students and teachers in the school using the stairwell, or by surveying their classmates? Would this change their engagement in the activity? Would it improve their solution? These are the sorts of questions we encourage teachers and researchers to consider in the design and implementation of engineering curricula.

Engineering for Characters in a Book

As previously mentioned, much of engineering is about solving problems for people. Again, it may appear too difficult to provide authentic clients for engineering problems in an elementary classroom setting. However, the intention to have a design address for a client's needs can be achieved in other ways. For example, in our Integrating Engineering and Literacy project students use fictional texts with richly developed characters to solve problems for (McCormick & Hynes, 2012). These fictional texts go much further than most teacher or curriculum generated engineering problems in their descriptions of characters and settings. The authors of these fictional texts did not write with the intention of people exploring problems that could be solved through engineering, which means that the author was not making choices with some engineering agenda to bias the story. The following excerpt comes from a fourth grade class that was engineering solutions for the brother and sister duo from the book *From the Mixed-up Files of Ms. Basil E. Frankweiler*. The characters in this story, Claudia and her younger brother Jamie, had run away from home to the New York Metropolitan Museum of Art and faced a number of problems as they tried to remain inconspicuous in New York City and solve a mystery at the museum. In the excerpt below, Mike and Thomas discuss which material they should use to construct a periscope that Claudia and Jamie could use to get a better view of the mysterious statue in the museum.

> Mike: Do you wanna make this out of wood?
> Thomas: Hmm… wood would be more artificial, but it would take longer.
> Mike: It would take longer, but it would be stronger.
> Thomas: But how would they… how would they get the wood?
> Mike: Do they have to?
> Thomas: Yeah, but if they get… you know how Jamie is really cheap?
> Mike: He is.
> Thomas: So if they wouldn't probably get the wood. They would probably get cardboard. Cause…
> Mike: Yeah. I see what you're saying. I see what you're saying.
> Thomas: Cause Jamie's cheap and that would probably cost a lot more than cardboard
> Mike: But then cardboard wouldn't be as sturdy and you know how flimsy cardboard is (shrugs).
> Mike: Yeah I mean um (drawing).
> Thomas: But then they…once they get the wood they'd have to get the cardboard. They'd have to get glue. They'd have to get all this other stuff.

As the pair discuss the best material for the periscope, Thomas introduces the client, Jamie, and the fact that he is cheap. This leads the pair to consider the tradeoffs between the structural properties of the materials and the cost and feasibility of procuring the materials. In doing so, Thomas and Mike now have to consider constraints outside of those imposed by the physical world, much like engineers do as they consider the needs of their clients. In another classroom, we see a pair of girls placing the comfort of

Shiloh, a dog, above the testing requirements defined by the teacher. In this excerpt, Stephanie and Alyssa are talking to one of the project researchers about the miniature dog pen they are designing for Shiloh, from the book *Shiloh*, and how it will be tested.

> Alyssa: Yeah, yours is awesome. Did yours make it through the tests?
> Oliver [from another group]: Not yet.
> Researcher: How are you guys testing it?
> Stephanie: Um, over there, I don't know what she's [the teacher] doing.
> Researcher: How do you think you'd wanna test it?
> Alyssa: I think she's gonna take, like, a little wind-up toy [vibrating Hex Bug™ toy], and it's just gonna walk around and it can't, your thing can't fall over.
> Stephanie: Well this is felt, so I don't even know if it [vibrating Hex bug toy] would be able to walk. But the felt is good, cause then it's soft.

Alyssa and Stephanie demonstrate that they know their prototype may not work so well when it is tested because of the felt lining they included in their pen. However, this does not appear as a concern for them as they state, "But the felt is good, cause then it's soft." In this moment, their attention is on Shiloh's comfort, and not on the seemingly arbitrary test, placing a vibrating Hex™ bug in the pen and seeing if it remains contained in the pen.

In both these examples the students self-impose design requirements they have created in their consideration of the clients for whom they are engineering. In both cases, the students appear to be authentically concerned with these requirements and are making design decisions that rely on the consideration of multiple factors. These factors appear to be psychological in nature where the students are trying to take the perspective of their users and design for what would be most pleasing for them.

In order to meet human centered goals, engineers must be aware of human phenomena and apply knowledge of such phenomena (i.e., humanities and social sciences). However, applying this kind of knowledge is rarely systematically integrated into engineering curricula and is often treated as a tertiary body of knowledge and skills for the engineer in training. We argue that inclusion of authentic opportunities to consider clients' needs and attributes while engineering can benefit students' engineering abilities and knowledge as well as their views toward engineering, and has been shown to be effective at the college level (Zoltowski, Oakes, & Cardella, 2012). Several questions arise when we consider the examples above. How are the students framing what they are doing in these situations? What are the types of knowledge and experience they are drawing on throughout the project? How are they balancing the tradeoffs client needs and technical execution? And how does this sort of engagement shift their conception of what engineering is?

Engineering with Classmates

Classrooms of students, similar to engineers in industry, generally work in teams as they engage in engineering design challenges. One challenge that arises in the elementary classroom is the negotiation of which ideas to incorporate from the various team members. Below Caitlin describes how she and her partner worked together.

> Caitlin: Well, we've been combining our design. See, I had one where there's layers, and I wasn't really good at thinking this out. And she [her partner] thought about his one house, so we were thinking we were going to make the layers the maze and this little drop thing, and if the German shepherd tries to get in, this thing will drop, like if he tries to pound on the doors, and there's a little scanner, just in case Judge Travers comes by, he'll scan his hand and then he'll fall through the dish too, and he'll find all these tunnels and he'll have to get out, and by the time he gets out he won't know where he is.
> …
> Caitlin: Because even though we had pretty similar ideas, like she had things like the speaker on the necklace and I thought that was a good idea, and he had the door stuff, and she was thinking it's a good idea to have layers because what if the German shepherd actually happens to dig through one layer or something like that?
> …
> Caitlin: We combined it because mine had extra things but I couldn't find what I want in the inside and she actually had a really good idea for the inside, so that *combineded* our idea really and mixed it really well. And I was thinking that there's an invisible roof right here so he can still feel the sun but the water won't come crashing through.

Caitlin appears to be explaining a process by which she and her partner evaluated each other's ideas, with the utterances "Because even though we had pretty similar ideas…" "I had one where there's layers, and I wasn't really good at thinking this out," and "she actually had a really good idea for the inside." Then, after this evaluation, took the best parts of their individual solutions to move toward a better solution, with the utterances, "Well, we've been combining our design." and "…so that *combineded* our idea really and mixed it really well." Solving engineering problems requires knowledge from a variety of domains and benefits from multiple perspectives.

Caitlin and her partner, working as engineers, incorporated aspects from each other's designs to optimize their solution and made decisions informed by their differing viewpoints, which are the sorts of negotiations engineers make all the time (Bucciarelli, 1994).

In addition to the benefits of having multiple people with diverse perspectives working toward a solution, research highlights how important interpersonal and social dynamics are to engineering (Hacker & Kleiner, 1996; Hammond et al., 2001; Stempfle & Badke-Schaub, 2002) and that engineers' communication, in varying forms (Harvey & Koubek, 1998), and organization are important for effective engineering (Smith & Leong, 1998). Professional engineers communicate with each other throughout the process to "stay on the same page," understand their failures, resolve disagreements and challenges, and reflect on their process (Smith & Leong, 1998; Stempfle & Badke-Schaub, 2002). The excerpt below, again from Caitlin and Anna, emphasizes that social dynamics need to be developed and practiced. In this excerpt, Caitlin and Anna have just tested their dog pen in front of the class and are now sharing with the class about what they just experienced. Their dog pen successfully survived a test where a car, representing a dog, crashed into it.

> Ms. Smith: 5-4-3-2-1. Engineers, talk about what you just experienced.
> Anna: Well, I didn't think that would happen, because I thought this would be really strong, but I guess maybe if we taped it a little better…
> Caitlin: I thought that at first…
> Ms. Smith: Hold, on, let's let Anna finish.
> Anna: I was pretty surprised that it didn't like go over the fence, but…
> Caitlin: I was pretty surprised that it actually held up. I thought it was just going to break the second the car touched it because I was feeling since we actually didn't get to finish and everybody else finished…
> Ms. Smith: There are people who finished it, who had their project too, also things got, it destroyed parts of their project.
> Caitlin: I felt kind of jealous of other people, like Thomas, Cooper, and Jack, they had a really interesting project, and I got kind of like, "oh, I wish I finished it like that."
> Ms. Smith: Um-hm. So what might you do next time.
> Caitlin: Try and not just spend all of our time thinking and being like "no, that won't work" and just instead just probably using more cardboard and trying to stop planning and just get the materials as fast as I can, not just kind of rush it, but kind of like get them on better and not just kind of sit around waiting.
> Ms. Smith: We need to create a balance between the planning process and the doing process, right? We need to kind of create a balance, make sure we're not spending too much time doing one or the other but balancing them out.
> Caitlin expressed disappointment and jealousy stemming from comparing her group's work to other groups in the class. Continuing on with this discussion, Anna, expresses her frustration with Caitlin's negativity during the project.
> Anna: I, um, well I really, the fact, I didn't really like the negativity that Caitlin had, cause many times she would say, it won't work, we're not going to have enough time, and it just felt really hard for me because I couldn't stay positive while my partner was so negative.
> Ms. Smith: So how did you balance that out?
> Anna: Well, I was just trying to explain to her, stop being so negative because we're going to finish it, we're going to finish it and no matter how it looks, I really think, more fun, but, um, I did feel like Caitlin was really negative.
> Caitlin: Cause I was trying, because of that first, because I noticed that people were already finished on the first day, and we only had, and then on the second day we had to take all of it apart except for this one wall, so we had to start over and like "oh my god."
> Ms. Smith: And sometimes we have a tendency to get really, really, really wrapped up with an idea of finishing, finishing, finishing, when the idea was to experience the design process. Did you get to experience the design process?
> Anna: Yeah, but I wish had experienced it in a more positive way.
> Caitlin: Yeah, I wish we had more time and more materials.

Here we see that the social dynamics played a significant role in the experience for both students. From an engineering perspective, we might call this a failed collaboration. We view this from the positive position that failure presents moments for learning. Engaging students in this sort of process early allows many opportunities to fail and iterate on what makes for a good collaboration. Unfortunately, within the context of engineering preparation, these sorts of opportunities often do not come until junior or senior-level project-based courses. However, we believe there is a real opportunity in K-12 engineering opportunities as K-12 teachers are well-positioned to use their social science knowledge and preparation as a foundation for developing engineering pedagogical content knowledge (Hynes, 2009) that integrates a more humanistic approach to engineering.

Research Implications

As previously noted, appealing to engineering students' desire to engage with or for people is not without precedent. Many curricular and extracurricular engineering activities are designed to work directly with real, human clients and promote collaboration and teamwork. Some of these programs have even documented that attention to social aspects were likely factors to their success (Coyle et al., 2006; Fisher & Mahajan, 2003; Fisher & Mahajan, 2010; Olds & Miller, 2004). However, there is little systematic research that investigates just how the social aspects of such programs contribute to such success or students' attitudes, beliefs, and abilities in engineering. Similarly, there is a dearth of research investigating how presenting a more people-centered approach in pre-college engineering influences younger students' beliefs, attitudes, and abilities with regard to engineering. What follows are two areas we put forward that are rife with opportunities for systematic research.

Attitudes and Perceptions

Much of the research into engaging K-12 students in engineering to this point has focused on measuring students' attitudes, beliefs, and perceptions of engineering where the goal of various interventions is to see improvement in these measures as programs look to increase the number of students entering the STEM pipeline. Many programs have been able to show promising results in exciting students by engaging them in appealing, hands-on activities (Brophy, Klein, Portsmore, & Rogers, 2008). However, it is unclear if this is because engineering activities provide a fun break from students' normal classroom activities, or because they are truly motivated by the opportunities to engineer. Results from various studies using the Draw an Engineer Test illustrate many naïve perceptions young students have and how engineering curricula and interventions change these perceptions (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Knight & Cunningham, 2004). However, there is little research that investigates the root cause of these shifts in attitudes, beliefs, and perceptions. Likewise, little research compares results across engineering interventions to elucidate the most promising strategies. We suggest that there is an opportunity to conduct deeper research in these areas, and to consider how the proposed framework of engineering for or with people contributes to shifts in students' attitudes, beliefs, and perceptions of engineering. Does foregrounding human-centered, social aspects of engineering impact males and females the same or differently? Does working for real clients change students' perceptions of engineering? Can the social aspects of engineering increase interest in engineering among a more diverse body of students? Feminist theory (Pawley, 2004), various statistics in college major choices, and gender studies from science (Haussler & Hoffman, 2002; Mann, 1994; Stadler, Duit, & Benkes, 2000) suggest affirmative answers to these questions; however, without studying such variables in the context of engineering interventions, opportunities are being missed to strengthen the case for more inclusive, appealing engineering activities for young students.

Skills/Ability to Engineer

Though specific goals vary from classroom to classroom and program to program (Brophy et al., 2008; National Research Council, 2009), we believe a primary goal of engineering education is to teach students how to better engineer solutions to complex problems. Developing proficiency in mathematics and science are certainly paramount to developing engineers' ability to efficiently and effectively solve problems, but how exactly does a strong background in the social sciences and humanities contribute to "better" engineering? We propose this as a fundamental question to be considered as engineering education in the K-12 classroom moves forward. Are Mike and Thomas, from the aforementioned example, doing better engineering by considering the specific needs and characteristics of their clients? What would their design for a similar challenge have been without being situated in the context of a book? Would their design decisions have been as richly informed? There is a great opportunity to expand our knowledge through research as ABET (2012) and college engineering programs move toward assessing broader professional skills centered on the integration of the humanities and social sciences with engineering.

Conclusion

We have proposed a construct outlining the humanistic side of engineering that we hypothesize can improve students' problem solving skills and attract a more diverse population into engineering-related fields. However, and this is a big however, we do not believe there is sufficient evidence to make any claims as to what and how big a role humanities and social science knowledge and skills should play in engineering education and urge others to consider systematically investigating how the inclusion of and focus on the humanistic side of engineering influences engineering learners. Although studies on learners' affects and perceptions are important, we believe much work is needed at an interaction level to investigate the nuanced dynamics of learners interacting within these socially-embedded contexts. With some creativity existing engineering design challenges can be revised to include aspects of humanistic engineering contexts, which can then be evaluated and researched to determine what sorts of impacts it may have on student learning and perceptions of engineering. We urge engineering educators and researchers to continue to push on the inclusion of the humanistic side of engineering as a critical aspect of learning engineering and forge new paths for research along these lines.

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