Exploring Ways to Develop Reflective Engineers: Toward Phronesis-Centered Engineering Education

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Abstract

The purpose of this work-in-progress research paper is to explore how engineering students' *phronesis* (ethical judgement or practical wisdom) can be fostered in an interdisciplinary graduate course that incorporates the arts and humanities. We present our research findings and implications from the data gathered from an innovative pilot course taught at a university in the south-central United States. Using the philosophical concept of *phronesis* as a guiding theoretical framework, we examined the writing of ten engineering graduate students who were enrolled in the course. The corpus of data included pre- and post-course essays, autobiographies, and samples of weekly reflective writing completed after reading about and discussing ethical dilemmas and other contextual considerations of engineering work. The data were analyzed inductively and deductively, generating categories and themes from coded data (bottom-up) as well as observing categories and themes implied in the course activities (top-down). The findings indicate preliminary signs concerning the students' development of *phronesis* through each week's learning activities. For example, they learned to be more open to others' ideas while simultaneously doubtful of their own thinking. They also became more attentive to the question of morality and ethics when considering engineering applications. Particularly, they learned to connect local engineering issues to broader implications. The significance of the study is three-fold: First, it shows an example of the value of educational theory and philosophy in advancing engineering education using the philosophical notion of *phronesis*. Second, the findings suggest the potential effectiveness of the curriculum that integrates the arts and humanities in cultivating engineering students' development of *phronesis* to become reflective practitioners. Lastly, the implications of our research provide future directions for improving and even rethinking engineering education.

Introduction

Efforts to realign engineering education to adapt to emerging engineering problems created by the changing society have taken place in almost every decade of the twentieth century, beginning in the early 1900s (National Academy of Engineering, 2005, p. 14). With varying scopes, these efforts are still ongoing not only in undergraduate education and but also in graduate education. For example, in 2004, the National Academy of Engineering (NAE) of the National Academies in the U.S. published their research outcomes of the Engineer of 2020 Project. The goal of the project was to use the research findings to "envision the future" (NAE, 2004, p. xi) in order to adapt engineering education to the new century. However, here we are in 2019, one year short of 2020, and we wonder how much progress has been made in addressing the discrepancy between engineering education and real-life engineering practice in industrialized countries, such as in the United States (Bucciarelli & Kuhn, 1997), Australia (Copeland & Lewis, 2004) and Denmark (Christensen & Ernø-Kjølhede, 2006). Engineering education may well prepare students as specialized individuals possessing sophisticated knowledge of instrumental methods and scientific principles, but perhaps it still fails to prepare students for complexities and uncertainties of engineering practice in real contexts (Bucciarelli & Kuhn, 1997). We have found that most graduate engineering curricula continue to focus on

technical concerns at the expense of the broader social, human, environmental, and ethical context of engineering (Copeland & Lewis, 2004); however engineers need such meta-disciplinary knowledge to see the legitimacy of contextual problems and to deal with those contexts effectively (Christensen & Ernø-Kjølhede, 2006).

In an effort to close the gap between engineering education and education practice, we formed an interdisciplinary team of scholars from engineering, psychology, and education. We are encouraged by the NAE (2004), who espoused interdisciplinary learning for engineering successes. We have been involved in an ongoing collaboration on an "experimental" curriculum that incorporates essential perspectives from the arts and humanities in engineering students' learning activities. The general aim of the curriculum is to enable engineering students to become reflective thinkers who develop the habit of critically thinking about the broader social, human, environmental, and ethical context when discussing problems and making decisions in their engineering practice. In so doing, the goal is to help engineering students foster their *phronesis*.

The purpose of this work-in-progress research paper is to explore how engineering students' *phronesis* was fostered in our experimental interdisciplinary graduate course, which incorporated the arts and humanities. The study is aimed at answering the following research question: In what ways has the interdisciplinary engineering course contributed to the students' development of *phronesis?*

Description of Pilot Course

The interdisciplinary graduate course through which we piloted our project was a one-credit seminar offered in 2017. About a dozen graduate students initially enrolled from civil and environmental engineering at the master's and doctoral levels. The course met weekly, each session lasting for about 90 minutes, during which time we typically introduced a topic with a brief talk, video, or guest speaker, then we read selected articles, and held a group discussion about potential ethical dilemmas. Also, as a part of most class meetings, we incorporated the practice of Visual Thinking Strategies (VTS), a technique that uses visual art to help students learn to express opinions shaped from detailed observation of the art using evidence to support their statements (see Yenawine & Miller, 2014). Other arts- and humanities-based activities we used included writing an autobiography, reading/discussing a novel that had a strong environmental justice theme, and writing weekly essays with either a focus on the broader contextual implications of the week's topic or with an open-ended reflection on the activity and/or content. To keep this paper closer to suggested length guidelines, only a small selection of our prompts and course materials is provided in the Appendices (more is available on request).

Literature Review and Conceptual Framework

Reflective inquiry has traditionally not been valued as a legitimate form of professional knowledge in the field of engineering since professionalism here is still mainly identified with technical expertise. That is, engineering is among the learned professions that typically follow the model of *Technical Rationality,* which prioritizes professional knowledge that is generalizable, scientifically verifiable, standardized, technologically driven, and applicable to a specific problem (Schön, 1983). According to American philosopher Donald Schön (1983),

technical rationality itself was grounded in *Positivism*, the perpetuating philosophical stance that emerged as a way to celebrate the triumphs of science and technological advancement in the industrial age of the nineteenth century. In the Positivistic epistemology, anything that did not have to do with scientific thought and technological practice, including religion, mysticism, emotions, and intuition, was counted as pseudo-knowledge. It was August Comte in the nineteenth century who founded Positivism with the three principal doctrines: (1) empirical science is the only source of positive knowledge of the world; (2) superstition, mysticism, intuition, and subjective experience are not considered true knowledge; and (3) scientific knowledge and technical control need to be applied to promote the well-being of mankind (Schön, 1983). Since then, technical rationality operating within these three principal doctrines has become the model of what counts as science and engineering knowledge.

However, Schön problematizes the overreliance on technical rationality in knowledge production and educating professionals. He expounds on his philosophy of Reflection-in-Action in his seminal book, *The Reflective Practitioner* (1983). He uses a road metaphor to point out how the Positivistic technical rationality cannot be used as the sole framework for educating professionals. He writes, "in the varied topography of professional practice, there is a high, hard ground where practitioners can make effective use of research-based theory and technique, and there is a swampy lowland where situations are confusing 'messes' incapable of technical solution" (p. 42). When graduate students in engineering are taught to become practitioners who walk on a "high, hard ground," they may function well as technical experts who can fix technical problems, but they may not function well in actual reality in a local setting in which problems are complex, uncertain, instable, unique and particular, and value-conflicting. A sole application of general theories and principles may not be possible in solving real life engineering problems. When there is a gap between professional knowledge and the demands of real-world practice, students who take the "high, hard ground" may intentionally discard data that fall outside their professional knowledge and select the data that only fit the model of their professional knowledge without further reflecting on possible repercussion of the choice. They may refuse to walk on a "swampy lowland" (p. 42) dealing with dilemmas and complexities but instead become engineers who overly rely on "technological fixes" for the complex social problems of energy and environmental quality, for example. Schön proposes the idea of reflective practice as an alternative to the traditional epistemology of technical rationality and posits *reflection-in-action* as a way to complement the limits of technical rationality.

A practitioner who engages in reflection-in-action is the one who does not hesitate to walk in the "swamp," questioning not only their own assumptions and techniques but also the values and purposes. Faced with dilemmas and complexities of a unique case, they are not dependent on the categories of established theory and technique but are able to construct a new theory for the unique case based on reflection, which requires one's *phronesis*. Engineers who choose to walk in the "swamp," and whose ultimate goal is to improve the society in which we live, recognize the limitations of pure technical solutions that may doom them to failure or at least limited success.

In the field of teacher education, for example, 'neo-Aristotelianism' has been revived in the last decade, with a focus on *phronesis* (i.e., moral/ethical judgment and practical wisdom) that connects educational practice and reflection to practice. The main purpose of this retrieval of certain Aristotelian insights into *phronesis* is to seek a paradigm of reflection grounded on the

ancient conception of virtue and the practice-embedded theory of practitioner knowledge, rather than the practitioner proof mode of knowledge (Birmingham, 2004; Dunne, 2005; Kim, 2011, 2016; Wong, 1995; Kristjansoon, 2005). In the *Nicomachean Ethics* (1985), Aristotle posits that there are three human dispositions (see Figure 1): *episteme* (epistemology, theory, or knowledge), *techne* (techniques or skills), and *phronesis* (ethical/moral judgment, practical wisdom, or prudence), and out of these three dispositions, *phronesis* is the highest virtue that humans should aspire to possess. For Aristotle, *phronesis* is a moral and intellectual virtue rooted in a natural human capacity "to do the right thing in the right place at the right time in the right way" (MacIntyre, cited in Carr, 2004, p. 62). *Phronesis* is moral judgment to act wisely and prudently, which is more than the possession of *episteme* (general content knowledge) or *techne* (how-to's, skills, or techniques) (Kim, 2011). *Phronesis*, according to Aristotle, is deeply related to deliberation that requires reflection. It calls for reflection that is concerned with the ability to put into action the general knowledge and skills with relevance, appropriateness, or sensitivity to a particular context (Dunne, 2005). Consistent with Schön, it is a capacity that a practitioner can acquire only through reflection, action, practice, and practical experience.
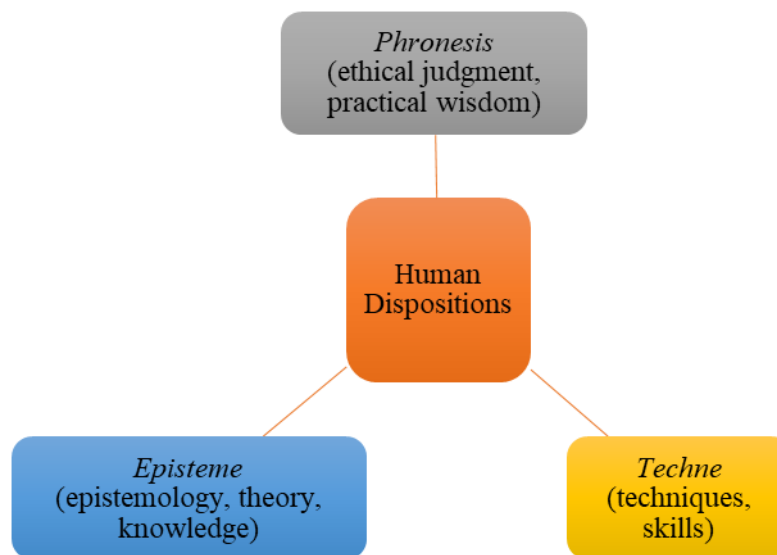

Figure 1. Graphic illustrating Aristotle's three human dispositions:
Phronesis, Episteme, & Techne.

It is within this conceptual framework that we are creating and researching the effects of an innovative curriculum that cultivates reflective engineers in a graduate program in engineering. Engineers will encounter many occasions requiring them to exercise not only their knowledge and skills but also *phronesis* as they work on advancing society for humankind. However, developing *phronesis* does not appear to have been an explicit or systematic part of the engineering curriculum. It is our premise that if we continue to train future engineers solely in the model of technical rationality, we may shortchange their capacity to effectively address societal challenges that require students' *phronesis* (ethical judgment or practical wisdom), which is more than technological knowledge and skills. Clearly, there is a need for innovative graduate courses that will transform the way we understand what it means to be an engineer in

the 21st century. It is our aim to help our graduate students become reflective engineers who use their *phronesis* to take conflicts and dilemmas more seriously in order to meet the ultimate goal of engineering: to find ways to make the world a better place.

Reflection in Engineering Education Literature

Various forms of reflection have surely been practiced and promoted by engineering educators around the world for centuries. However, considering that "engineering education research (EER) generally lacked definition as a discipline until the late 1990s and early 2000s" (Johri & Olds, 2014) relevant literature on graduate-level engineering education prior to the 1990's can be difficult to find. This review will focus primarily on literature of the past decade because it is both more readily available and more relevant to our study of contemporary graduate engineering education. Furthermore, since a detailed review of the literature on reflection in the proceedings of the American Society for Engineering Education (ASEE) annual conferences was provided by Sepp et al. (2015), this sub-section will focus primarily on literature outside the U.S. from the proceedings of the European Society for Engineering Education (SEFI). Considering the frequency in common use of variants of the root word reflect (i.e., for reflection, reflections, reflecting, and reflective) and of the related root word reflex (i.e., for reflexive and reflexivity), we confined our search to the titles of these papers. We removed duplicate listings and titles that were clearly irrelevant, such as those addressing reflection in the sense of electro-magnetic waves. Our intention here was to provide a broad overview of the interest given to reflection in this selection of the English language literature.

A search of all available years (2008 to 2018) of the annual conferences of the European Society for Engineering Education (SEFI) returned 20 unique titles indicating potentially relevant papers. Of these, five appear to be directed at the graduate-level. The first and second (Jensen, 2008; Jensen 2009) reported on the use of reflective learning journals in the context of a master-level engineering course involving problem-based learning with teams of Danish and international (i.e., non-Danish) students. Using examples from these learning journals, the author attempted to show that the students attained the course's learning goals regarding team work, intercultural skills, and ability to reflect. The second paper was a follow-up to the first, based on two years of experience and having analyzed 71 learning journals (called portfolios there-in) with a focus on intercultural awareness and the reflections students shared about how to prepare for and initiate intercultural teamwork in a problem-based learning environment.

The third paper (Andrews, Clark, & Glew, 2011) introduced an empirical study investigating challenges associated with embedding reflection and reflexivity into a work-based master's level professional engineering program in the U.K. Using an exploratory Action Research methodology involving Narrative Analysis, the authors concluded that while "engineers may struggle with the concepts of reflection and reflexivity, with support and encouragement such difficulties can be overcome" (p. 4). The fourth paper (Glew, 2014) described the model of critical reflection that has been used at the Master- and Bachelor-degree levels in these same U.K. work-based programs. Their "triple mode learning model" incorporates Schön's (1983) idea of "theories in use" with experiential learning to integrate theory with practice through a cyclic process of imitation, experience, and reflection.

Finally, the last paper (Baier & Pongratz, 2013) described an innovative course and support network known as "Blue Engineering" that was initiated by engineering students

themselves in Germany. The purpose of Blue Engineering is to collectively and critically reflect on technology and society, providing a collaborative approach to ethical considerations. Blue Engineering attempts to transcend theoretical discussions and aspires to gradually change the very concept of engineering by "exploring and expanding one's liberties at university and work" (p. 2) to create a sustainable world where resources are shared and evenly distributed. While the authors did not clarify whether the students who created this program were graduate or undergraduate students and for whom it was intended, the ideas are clearly relevant to and appropriate for graduate programs and they share common ideals and motivations with our work as well as the techniques of reading and ethical discussions.

For the sake of comparison with the annual conferences of the American Society for Engineering Education (ASEE), a similar search of all available years (1996 through 2018) returned 169 unique titles indicating potentially relevant papers. Most of these were written in the last 10 years, which follows the trend that Sepp et al. (2015) observed in their detailed and systematic review of the ASEE conference proceedings from 1996 through 2014. This "upward trend" has continued as shown in Figure 2, which provides a coarser measure of interest in reflection than Sepp et al. Here it is measured simply by number of paper titles in the ASEE Annual Conferences from 1996 to 2018 that contain words related to reflection (i.e., reflect(s), reflecting, reflection(s), reflective, reflexive, or reflexivity). The large jump overserved in 2015 may be due to the efforts of the Consortium to Promote Reflection in Engineering Education (CPREE http://cpree.uw.edu), an initiative led by the University of Washington in collaboration with 5 other institutions of higher education in Washington state, 2 in California, and 1 each in Arizona, Georgia, Indiana, and New York. A possible cause for the more gradual increase might be growth in engineering education at the K-12 level: although engineering education has historically been reserved for the university, this is slowly changing as engineering is increasingly being taught in pre-university settings (NAE & NRC, 2009).

Phronesis in Engineering Education Literature

While the concept of reflection, as shown in the previous subsection, has received considerable attention in the engineering education literature, this does not appear to be the case for *phronesis*. A full-text search of the conference proceedings for the American Society for Engineering Education (ASEE) from 1996 through 2018 returned only six papers that even mentioned the word *phronesis* (none in paper titles) and each of these gave only a single mention of the term. For example, in two of these papers, *phronesis* appeared because it was quoted in the writing of others in the context of practical deliberation (Khan, 2001) and of deliberative reasoning (Shelley & Santarelli, 2010). In the case of Weedon (2016), *phronesis* was recognized briefly as a part of a more complex "engineering judgement." In the case of Riley (2014) and Chan et al. (2018), it appeared with Aristotle's *episteme* and/or *techne* alongside the common translation of "practical wisdom."
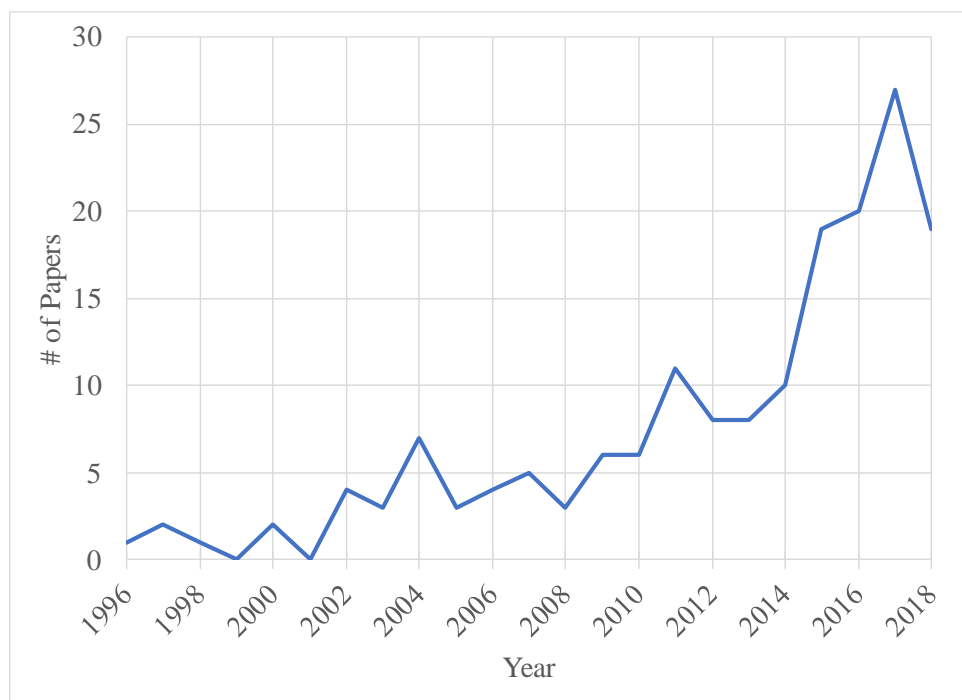
Figure 2. Line chart showing increase in academic interest in reflection as measured by paper titles containing words related to reflection (i.e., reflect(s), reflecting, reflection(s), reflective, reflexive, or reflexivity) at ASEE Annual Conferences from 1996 through 2018.

Even a search using that common translation returned very few hits and nothing new that was relevant. If we expand our search to include the ASEE's major journal publication, the Journal of Engineering Education, a full text search from 1993 to 2018 returns only a single article (Jamison, Kolmos, & Holgaard, 2014) that contains the word once in a similarly brief fashion. In all cases the term has been used only in passing. This suggest that few in the engineering education community have striven to deeply understand the term and fewer still have attempted to operationalize it or explore it empirically. Indeed, we must venture out of engineering education research and into the realm of engineering ethics (a branch of applied ethics in the field of philosophy), to find serious consideration of *phronesis* in the context of engineering. For example, Davis (2012) was cited in Weedon's (2016) definition of "engineering judgement" and provides a deeper understanding of *phronesis* as it relates to judgement in engineering (noting that the two concepts are not the same).Given that most literature in engineering ethics is far more conceptual than empirical, the present paper can begin to bridge the gap.

Mode of Inquiry and Methods

We used a descriptive case study (Yin,1994) to investigate how the *phronesis* of a group of engineering students can be fostered in our experimental interdisciplinary graduate course that incorporates the arts and humanities. The study sought to get "an in-depth understanding" (Schwandt & Gates, 2018, p. 343) of the perceptions and possible identity transformation or development of a particular case of a student group within its natural context to generate knowledge and inform professional practice. The process and product of inquiry about this case

looked to the "descriptive" (Merriam, 1998, p. 29) aspects of the case, which meant that it would report findings of the research in a literary way and from a wide variety of sources (Brown, 2008). Doing this intrinsic case study (Stake, 1995), our first obligation was not to build theory or to generalize it to other cases, but to understand "the particularity and complexity of a single case" (Schwandt & Gates, 2018, p. 342) and therein aspiring to provide readers with "good raw material for their own generalizing" (Stake, 1995, p.102).

This research study was conducted with approval of the university's Human Research Protection Program. By the end of the semester, complete coursework was available from ten of the student participants (designated Student 01 through 10). This group of students included seven women and three men, and half class were international students, making a diverse group of participants. The data we examined included responses to pre- and post-course essay questions on the topics of reflection, ethics, and broader considerations in engineering, student autobiographies, and samples of their weekly reflective writing, which they completed after reading about and discussing ethical dilemmas and other contextual considerations of engineering work. The data were analyzed inductively and deductively, generating categories and themes from coded data (bottom-up) as well as observing categories and themes implied in the course activities (top-down) (Erickson, 2004).

Findings

The data analysis indicated substantial findings concerning the students' development of *phronesis,* their ethical judgment through each week's learning activities. Specifically, they became more critical and reflective in their thinking and writing by developing the abilities of: (1) competence in contextual knowledge, (2) tolerance of ambiguity, (3) and openness to critical reflection. We will discuss each of these themes in more detail below.

Competence in Contextual Knowledge

A practitioner's contextual knowledge is the tacit knowledge that resides "in the practitioner's ability to find and interpret subtle cues where outsiders see no information" (Christensen & Ernø-Kjølhede, 2006, p. 10). Competence in contextual knowledge in engineering, then, reflects an engineer's ability to "anticipate and understand the constraints and impacts of social, cultural, political, and other contexts on engineering solutions" (Ro, Merson, Lattuca, & Terenzini, 2015). In the students' terms, contextual competence may be defined simply as "thinking large," "having a holistic viewpoint," and "not taking things at face value" (Student 03). Some of them also had their own general definition of contextual competence, such as "considering the broad scope of cause and effect solutions that have minimal social, cultural, economic, political, and ethical consequences as well as maximum benefits" (Student 05). Students demonstrated their ability to picture "the complex facets of a problem [which go beyond the technical aspects of their] comfort zone" (Student 01) while taking into account the moral and ethical responsibilities of their decisions in order to reach compromises and solutions. More sophisticatedly, they showed the realization of the "interrelatedness of many aspects of life" (Student 02), which requires an engineer to develop as "a whole person who is responsible to the Earth" (Student 07). A whole person to the students is one who is "willing to consider the effects of [his/her professional] decisions … on the community and society and people" (Student 07). The following excerpt, from a week 6 reflection paper about the National Academy of Engineering (NAE) Grand Challenges for Engineering and Riley's (2012) critique of it, showed

the students' sophisticated knowledge of the complexity of modern life that requires of scientists and engineers more than professional knowledge and skills:

> "The lack of professionals in the field of engineering ethics in the [composition of NAE] experts [who generated the Grand Challenges] further revealed the incomplete consideration [inherent in the Grand Challenges]. I would like to [discuss] this perspective by addressing the side effects of technological developments. [Is] all new technology good for the human beings? The answer is probably not, for instance, when you think of the development in the weapons and ammunitions. Stronger, more powerful military is under development in every country, and it certainly makes the civilians feel safer. But conflicts among difference ethical [ethnic?] groups, countries due to religion, economic considerations etc. are always present. One solution for these conflicts has always been suppressions through violence. Someone is going to be severely hurt by the innovation and development in the weaponry technologies. The example above might be extreme. Another good example is the e-waste issue we had talked about in the beginning of this semester. People in the first world are always attracted to more advanced electronics. But the technological development in the electronic industry driven by this consumerism will lead to more e-waste that has to been dealt with by the third country. The decision-making process based only on opinions from scientists and engineers seemed a little single-minded and lacked a flavor of humanity."   —Student 07

Thus, Student 07 discussed at length how engineers cannot just rely on the "effects of technological developments." The student asks, "[Is] all new technology good for the human beings?" and shows concern about how "someone is going to be severely hurt by the innovation and development in the weaponry technologies." The last statement made by Student 07 is of particular interest as the student concludes, "The decision-making process based only on opinions from scientists and engineers seemed a little single-minded and lacked a flavor of humanity." This indicates that the student recognizes the limitations of technical rationality that undermines what it means to be human. For another example, Student 04 also pointed out the importance of enacting *phronesis* by writing "I should reevaluate myself to ensure that I am being ethical at all times" and "I just want people to care and be passionate about the struggles that occur within environmental issues."

Tolerance of Ambiguity

Although ambiguity may create confusion and uncertainty of not-knowing, it also provides room for imagination that is critical in solving engineering problems. Anthropologist, Bateson states, "Ambiguity is the warp of life, not something to be eliminated (cited in Clandinin & Connelly, 2000, p. 9). Complex real-life engineering problems are inevitably ambiguous and unpredictable, which require engineers to develop tolerance and even embrace the notion of ambiguity.

The students in this study gradually learned to be more aware and tolerant of ambiguity rather than trying to reach the 'right' answers. Through the class activities, the students saw "the ambiguity in things depending on different perspectives" (Student 09) and realized that "the reality is that many engineering dilemmas do not have perfect solutions when all aspects are considered" (Student 05). More importantly, they learned of the need to have support from non-scientific people by thinking less technically and more socially, culturally, and politically in

analyzing and solving technical problems (Student 05). In particular, the Visual Thinking Strategies (VTS) exercises (see Yenawine & Miller, 2014) that we implemented as part of our pilot course seemed to help students "recognize a discomfort with ambiguity" (Student 01) in themselves. Moreover, VTS may have helped some students learn to idealize the need for bigger-picture contexts and complex questions of ethics and morality rather than idealizing the role of the engineer who lacks critical examination of their products and the stakeholders being served, as Student 01 wrote,

> "I would say that the visual thinking exercises helped me recognize a discomfort with ambiguity in myself. I think realizing that and the potential ramifications that has is an important take-away from the course so far. I did not know what to expect from the VTS portion of the course, so that has been an interesting area of growth for me. Another area that I have been made aware of through the course so far is my tendency to idealize the role of the engineer, to be swayed by bold statements such as the Grand Challenges without critically examining their creation and the stakeholders either being served. Conversely, I see a tendency within myself to idealize the need for bigger picture context and complex questions of ethics and morality to be asked continuously when considering engineering applications."   —Student 01

Another example of how the VTS activities had changed the student's perception of ambiguity is provided by Student 07, who wrote,

> "Getting to know VTS had been a very exciting experience. I used to feel uncomfortable when experiencing ambiguity. When I could see different meanings in a painting in a museum, naturally I was drawn to force myself to pick one meaning. After I saw a good movie, I always would try to conclude what was the director's purpose on doing a certain shot, and I always would tend to add some significance and revelation on the ending. Now I have been taught VTS, I understand that not everything has to have a purpose, but at the same time things can also have multiple purpose and bring ambiguity to minds. I finally started to get comfortable with disagreements. Based on the class experience, I could also see how a person's educational background and personalities can affect what they see, which will help me more to understand where different ideas come from and get used to them."   —Student 07

The two student's narratives above show changes in thinking from having "discomfort with ambiguity" and feeling "uncomfortable when experiencing ambiguity" to understanding "not everything has to have a purpose, but at the same time things can also have multiple purposes and bring ambiguity to minds." One student even started to "get comfortable with disagreements." The tolerance and acceptance of ambiguity, as the student's writing indicates, seems to help students further tolerate and accept differences.

Another related example shows how the class activities also enabled some students to be more aware of biases in conducting research, which required the researchers to constantly reflect while doing research:

> "But prejudice is inevitable, and I admit I have [a] biased view on the research techniques used by less-technology oriented majors. What concrete conclusions can be drawn from

just a bunch of surveys? How serious were the survey takers so that they were offering honest and well-analyzed answers? After all, what the researchers in art majors, such as human resources and education, are trying to measure is people's emotions and feelings, and how could one quantify those? If you cannot quantify something and generate a trustworthy conclusion, then what is point? However, I learned from today's discussion that the purpose of some research, especially the research in art majors, is not to find an answer, but to generate more questions. That is especially true in the social issues, because they often cannot be solved with an easy answer. If the research is able to get more minds, particularly these minds with higher "impact factors", thinking about the topic, it will be considered as a success because thinking brings attentions and attentions bring actions."   —Student 07

Thus, Student 07 first identified with the Positivistic epistemology of technical rationality by raising questions about how researchers "are trying to measure people's emotions and feelings, and how could one quantify those?" The student also adds, "they [social issues] often cannot be solved with an easy answer." The student shows the sign of developing her/his *phronesis* with which to question and challenge the taken-for-granted ideas about the overreliance on technical knowledge and solutions.

Openness to Critical Reflection

Critical openness reflects one's tendency to be actively open to new ideas, critical in evaluating these ideas and modifying his/her thinking in light of convincing evidence (Ennis, 1996). In our pilot course, the group discussion about potential ethical dilemmas in each class' topic proved to be meaningful for the students since it facilitated their open-mindedness to differences and new ideas. For instance, the class discussion not only "tangibly shaped [their] own perception of the issue at hand" (Student 01), it brought them joyful discovery in 'aha moments' as well as helped them gain "valuable insights from others" (Student 01) or get "educated" (Student 06) by others; making them feel optimistic toward a bright future when the engineering community involved "all these great reflective engineers coming along" (Student 01). They were well-aware that to be an engineer can be "potentially everything and actually nothing" without critical reflection on openness to areas outside their technical field. This finding was reflected in one of the students' writings about the dilemmas in the NAE Grand Challenges:

"[…] the true Grand Challenge of engineering is not simply to transform the world. It is to do so with critical reflection on what it means to be an engineer and what the real sociocultural and ethical needs are. In the words of a Spanish philosopher, to be an engineer and only an engineer is to be potentially everything and actually nothing. The advice to all engineers and non-engineers should be to reflect more deeply about what the real-life needs are of the society they dream to develop and live in."   —Student 06

Student 06 recognizes how critical reflection is crucial to the meaning of an engineer. For this student, deep thinking also involves "the ability to think critically and with wisdom," hence *phronesis*:

"Referring to the great Greek philosopher Aristotle, the term phronesis enhance[s] the argument of having ethical, critical thinking in order to face technical problems. Specifically, the term refers to the wisdom and critical attitude that one should have in

order to react and reflect. This can be applied to the technical rationality. For example, an engineer that wants to design a nuclear plant, not only has to follow the technical regulations to build a sustainable plant, but also has to take into consideration the impact that the plant will have to the population that lives near the plant. Reflecting with phronesis in action, is the clear message of the topic today. Having the ability to think critically and with wisdom, gives the strength to reflect and react not only as a routine action, but also as an action that has the best possible impact ethically and sociologically to the society."   —Student 06

Thus, Student 06 is able to provide a specific example of an engineer who needs to utilize their reflection with *phronesis* by stating that an engineer should be able to "take into consideration the impact" that the engineer's decision could make on the population.

Discussion

As discussed in the literature review section above, the actual reality of engineering contains not only 'high, hard ground' where engineers may function well as technical experts, but also "swampy lowlands" (Schön, 1983, p. 42) where situations are confusing and murky, incapable of technical solutions. By being exposed to multiple issues, conflicts, and dilemmas in controversial topics through multiple arts- and humanities-based conduits, the students showed some signs of growth, acknowledging the necessity of becoming reflective engineers and thus projecting their ongoing development of *phronesis*.

In accordance with our prior, preliminary research findings that the construct of contextual competence showed statistically significant changes over the semester for this group of students (Campbell, Reible, Taraban, & Kim, 2018), the findings in this paper also indicate that these students learned of the importance of an engineer's competence for contextual knowledge, i.e., they could imagine "the subtle cues" (Christensen & Ernø-Kjølhede, 2006, p. 10) inherent in each problem, dilemma, or issue they worked on. That knowledge reflects their good judgement about the complexity of their professional practices. The students entered the course assuming that engineering practice is heavily results oriented and therefore reflection involves examining technical calculations to reach the most efficient results (e.g., Student 01 indicated this in the pre-course essay). However, over the course of study, the students have learned to place their decision-making process, showing competence in contextual knowledge that goes beyond the technical knowledge to considering ethical, social, cultural, political, economic, and environmental impacts of their decisions on the people, the communities, and the wider society. Engineers who develop competence in contextual knowledge are whole persons, who not only self-actualize but also strive to be socially, emotionally, and ethically responsible for the world.

Learning to walk through Schön's "swampy lowlands" under the guidance of the professors in the pilot study, the students have experienced messy situations that taught them to be more tolerant of ambiguity rather than trying to reach the 'right' answers. They learned to accept that many engineering dilemmas do not have perfect solutions when all aspects are considered. In Schön's (1983) words, they have learned to be more attentive to "uncertainty, instability, uniqueness, and value conflict" (p. 50), which likely facilitates their ability to "cope with the troublesome 'divergent' situations of practice" (p. 62). The conflicts that engineers learn

to value come from the divergences inherent in every situation of engineering practice, i.e., technical, social, ethical, cultural, economic, political, human, and environmental issues.

The findings also present the students' development of open-mindedness through critical reflection. They learned to value not only the new knowledge from the varied class activities that were designed to foster their reflection, but also from class discussions in which other students' diverse thoughts were shared. Real-life problems are complex, uncertain, instable, unique and particular, and value-conflicting, and thus a collaboration among people of different perspectives and expertise is necessary, if not compulsory.

Conclusion

One of the recommendations that the NAE (2005) made in their 2020 Project was: "Engineering education must be realigned to promote attainment of the characteristics desired in practicing engineers, and this must be done in the context of an increased emphasis on the research base underlying conduct of engineering practice and engineering education. This will require that action be taken by key stakeholders, particularly engineering faculty and the engineering professional societies" (NAE, 2005, p. 17). What then would be the "characteristics desired in practicing engineers"? We try to find an answer in the philosophical concept of *phronesis*. We argue that one of the main characteristics desired in practicing engineers is a person who not only encompasses *techne* and *episteme* but also *phronesis* which can be developed through ongoing reflection. Engineering situations in reality require flexibility and fluidity in thinking, as they present formidable and unusual challenges. Then, it would be critical to reimagine engineering education with more humanities-oriented teaching and learning, which would help foster and cultivate engineering students' *phronesis*.

The significance of the study is three-fold: First, it shows an example of the value of educational theory and philosophy in advancing engineering education using the philosophical notion of *phronesis*. Second, the findings suggest the potential effectiveness of the curriculum that integrates the arts and humanities in cultivating engineering students' development of *phronesis* to become reflective practitioners. Lastly, the implications of our research provide future directions for improving engineering education.

In conclusion, we argue that engineering education should be *phronesis*-centered, with a strong focus on educating critically reflective engineers who have contextual competence, tolerance to ambiguities, and critical reflection to openness. We conclude our paper with a quote from one of the students:

"[T]he road to a reflective engineer will be something that will encompass my entire engineering career but I feel that I am much more aware now, and this class is a direct link to this positive lifestyle." —Student 03

One student at a time...

Acknowledgements

Appendix 1: Pre- and Post-course Essay Prompts:

1. What does the word reflection mean to you in the context of engineering practice? In other words, what does it mean to be a reflective engineer?
   Please provide a detailed response to the above question (e.g., a paragraph or two as needed). Please express yourself clearly, with a response that is organized and coherent. There is no "correct" answer.

2. What does the word ethical mean to you in the context of engineering practice? In other words, what does it mean to do something ethically as an engineer?
   Please provide a detailed response to the above question (e.g., a paragraph or two as needed). Please express yourself clearly, with a response that is organized and coherent. There is no "correct" answer.

3. a) What does the term "social considerations" mean in the context of engineering practice? Please briefly define and give an example.

   b) What about the following additional types of considerations: political, economic, cultural, environmental, ethical?
   Please briefly define and give an example of each.

4. How have social, political, economic, cultural, environmental, and ethical issues typically been considered in your engineering (or other) education? Please discuss each in turn.
   Please provide a detailed response to the above question (e.g., a paragraph or two as needed). Please express yourself clearly, with a response that is organized and coherent. There is no "correct" answer.

Appendix 2: Autobiographical Essay Assignment

Why autobiographical essay?

In the field of education, writing an autobiographical essay (writing about yourself and your lived experience) is considered an important learning activity. It is based on the premise that an autobiographical essay is a fundamental way to develop one's self as a person and a professional. It promotes the student's self-understanding through reflection and critical examination of one's life as lived and experienced. Writing an autobiographical essay is, therefore, the beginning of one's journey into developing the self, in which personal meaning is constructed and highly valued. Hence, this opportunity to write an autobiographical essay can serve you as a meaningful activity in teaching and learning, which documents your continuous effort and process to grow personally and professionally.

What am I supposed to do?

You are asked to spend some time reflecting on yourself and your lived experience. Write an essay about yourself in at least 750 words, but you're welcome to write longer, if you wish, up to 1,250 words (about 3 pages, single-spaced). It is a free writing activity in general, but you could use questions like the following as guides if you want to:

- Who am I?
- What experience has contributed to the person I am becoming?
- What was my childhood like?
- What was my school experience like?
- Which lived experiences have shaped or will continue to shape who I am as a person, a student, and a future engineer (or other professional)?
- What was the critical event or turning point in my life?
- What were or are the challenges in my life and how do I make sense of them?
- Who has influenced me the most in the decision to become an engineer (or other professional)?
- What kind of an engineer (or other professional) do I want to become?
- How do I perceive the society I live in?
- What is it that I want to do with a degree in engineering (or other field)?

Please submit your autobiographical essay electronically by the start of our next class following these requirements:

- 750 to 1,250 words (about 2 to 3 pages) in length
- 12pt, Times New Roman font, 1" margins all around
- single spaced with 1 line between paragraphs (no before/after paragraph spacing)
- writing should be clearly structured and coherent correct grammar and spelling are strongly encouraged

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