Fostering Reflective Habits and Skills in Graduate Engineering Education via the Arts and Humanities

Dr. Ryan C. Campbell, Texas Tech University

Having completed his Ph.D. through the University of Washington's interdisciplinary Individual Ph.D. Program (see bit.ly/uwiphd), Ryan is now a Postdoctoral Research Associate at Texas Tech University. He currently facilitates an interdisciplinary project entitled "Developing Reflective Engineers through Artful Methods." His scholarly interests include both teaching and research in engineering education, arts & humanities in engineering, interdisciplinary engineering, social justice in engineering, care ethics in engineering, humanitarian engineering, engineering ethics.

Dr. Danny D. Reible P.E., Texas Tech University

Dr. Danny D. Reible is the Donovan Maddox Distinguished Engineering Chair at Texas Tech University. He was previously the Bettie Margaret Smith Chair of Environmental Health Engineering in the Department of Civil, Architectural and Environmental Engineering and the Director of the Center for Research in Water Resources at the University of Texas in Austin. Dr. Reible holds a Ph.D. in Chemical Engineering from the California Institute of Technology, and is a Board Certified Environmental Engineer, a Professional Engineer (Louisiana), and was elected to the National Academy of Engineering in 2005 for the "development of widely used approaches for the management of contaminated sediments". His research is focused on the fate, transport, and management of contaminants in the environment and the sustainable management of water resources.

Dr. Roman Taraban, Texas Tech University

Roman Taraban is Professor in the Department of Psychological Sciences at Texas Tech University. He received his Ph.D. in cognitive psychology from Carnegie Mellon University. His interests are in how undergraduate students learn, and especially, in critical thinking and how students draw meaningful connections in traditional college content materials.

Dr. Jeong-Hee Kim, Texas Tech University

Jeong-Hee Kim is Professor of Curriculum Studies and Teacher Education in the Department of Curriculum and Instruction at Texas Tech University. Kim is a curriculum theorist, teacher educator, and narrative inquiry methodologist. Her research centers on various epistemological underpinnings of curriculum studies, particularly engaging in hermeneutical excavation of the stories of students and teachers around the notion of Bildung, a human way of developing or cultivating one's capacity. She received the Faculty Outstanding Researcher Award in 2018 from Texas Tech University, and the Outstanding Publication Award from the American Education Research Association in 2017 for her book, Understanding Narrative Inquiry, published in 2016 with SAGE. She has published numerous articles in journals including Journal of Curriculum Studies, International Journal of Qualitative Studies in Education, and Educational Philosophy and Theory.

Dr. Chongzheng Na, Texas Tech University

Chongzheng Na is an associate professor at Texas Tech University. He graduated from Tsinghua University (B.E.), Pennsylvania State University (M.S.), and University of Michigan (Ph.D.). Before joining Texas Tech, he was a postdoctoral fellow at Harvard University and an assistant professor at University of Notre Dame. His research and teaching interests include developing innovative water treatment technologies and incorporating knowledge related to such efforts in the environmental engineering curriculum.

Fostering Reflective Habits and Skills in Graduate Engineering Education via the Arts and Humanities

Abstract
Can the arts and humanities provide key perspectives for engineers in developing awareness of and interest in the environmental and sociotechnical impacts of engineering? How might essential habits and skills necessary for engineers to meaningfully address these impacts be learned using the arts and humanities? We are exploring such questions under a grant from the National Science Foundation to develop and assess a curriculum that explores methods of fostering reflective habits and skills in graduate students through activities involving the arts and humanities. Largely informed by the theories of John Dewey, Elliot Eisner, and Donald Schön, our experimental curriculum includes such activities as autobiographical writing with an accompanying art creation, reading about and discussing ethical dilemmas, practicing visual thinking strategies (VTS), writing weekly reflective essays, reading and discussing fiction with strong environmental justice themes, and even collaborating on art projects with graduate students in the School of Art. Incorporating aspects of the arts and humanities to complement engineering thought and action is a critical component of our work, which we describe as developing reflective engineers through artful methods.

In this paper, we present findings from two instantiations of a newly designed graduate course in civil/environmental engineering that integrates the arts and humanities. The objective of our course is to develop engineers who are more reflective than traditionally trained engineers and are thereby better able to: (a) understand and address the complexities of modern real-world challenges, (b) make better ethical decisions, and (c) serve the public not only with technical engineering skills but with mindfulness of and sensitivity to the complex social, cultural, and environmental contexts their work. Thus far, results have been encouraging from both our surveys (reported here) and our analyses of student interviews and writing samples (reported elsewhere). For example, aggregate results from the pre/post Likert-type surveys ($n = 19$) showed statistically significant increases in Insight, which is a metacognitive factor central to the process of purposeful & directed change ($p < 0.02$, $d > 0.3$) and in Contextual Competence, which is an engineering-specific measure of contextual understand ($p < 0.001$, $d > 0.8$). We also observed potentially significant increases in Reflective Skepticism ($p < 0.1$, $d > 0.3$), which is a measure of reflection regarding the tendency to learn from one's past experiences and be questioning of evidence, and in Interdisciplinary Skills ($p < 0.3$, $d > 0.3$). These self-reported survey results, despite the small number of participants, suggest clear potential that engineering students can develop their capacity for reflection through arts- and humanities-based activities.

Introduction

This paper describes the ongoing development and assessment of an innovative curriculum that explores methods for fostering reflective habits and skills in graduate engineering education through activities involving the arts and humanities. Largely informed by the theories of John Dewey (1915/2001), Elliot Eisner (2005), and Donald Schön (1983), our experimental curriculum includes such activities as autobiographical writing with an accompanying art creation, reading about and discussing ethical dilemmas, practicing visual thinking strategies (VTS), writing weekly reflective essays, reading and discussing fiction (e.g., novels, short stories, and poetry) with strong environmental justice themes, visiting museum exhibits, and even collaborating on art projects with graduate students in the School of Art. A critical effort of our work is incorporating aspects of the arts and humanities to complement engineering thought and action and thus to "develop reflective engineers through artful methods" (DREAM).

Thus, the objective of our course is to develop engineers who are more reflective in their work than traditionally trained engineers, and are thereby better able to:

- understand and address the complexities of modern real-world challenges
- make better ethical decisions
- make informed judgments that consider the impact of engineering solutions
- serve the public not only with technical engineering skills but with mindfulness of and sensitivity to the complex social, cultural, and ecological contexts their work

Can the arts and humanities provide key perspectives for engineers in developing awareness of and interest in the environmental and sociotechnical impacts of engineering? How might essential habits and skills necessary for engineers to meaningfully address these impacts be learned using the arts and humanities? We are exploring such questions under a grant from the National Science Foundation (NSF) to develop and assess a curriculum that explores methods for fostering reflective habits and skills in graduate students through activities involving the arts and humanities.

In this paper, we present findings from two semesters implementing the newly designed graduate curriculum in civil/environmental engineering. This work builds on and extends the brief findings presented previously from the pilot offering of the course (see Campbell et al. 2018) by aggregating the pre/post survey data set with the second offering to bring up the sample size to $n = 19$. Our overarching research goal is to explore how the arts and humanities might help engineers become more reflective thinkers with greater awareness of and sensitivity to the broader context of societal well-being and sustainability. Under this goal, we pose the following research question to address in this paper:

> RQ1: To what extent might participation in arts- and humanities-based course activities change the abilities of engineering students to engage in reflective thinking?

While this question is quantitative in nature and we focus here on Likert-type survey data to address it, note that this is only a fraction of the data we are collecting and analyzing as part of the larger mixed-methods study with additional research questions. Other data sources for ongoing and future analysis include responses to pre- and post-course essay questions (written just prior to completing these Likert-type surveys, e.g., see Campbell et al., 2018), interviews of student participants (e.g., see Kim et al., 2020), and various student essays and other coursework (e.g., see Kim, Campbell, et al., 2019; Taraban et al., forthcoming).

Description of Course

To begin answering our questions, we conducted research on two offerings of a one-semester (16 week) graduate-level elective course. While there were differences in structure and content between the two offerings (detailed below), both made significant use of Visual Thinking Strategies (VTS), so a brief introduction to VTS will be provided here.

VTS is a technique developed by cognitive psychologist A. Housen and museum director P. Yenawine that was initially designed to help school children stay engaged and gain more from educational programs at museums by fostering aesthetic development and visual literacy (see https://vtshome.org and Hailey et al., 2015). The VTS approach uses visual art to help students learn to express opinions formed from detailed observation of the art using evidence to support their statements. VTS has been shown to nurture not only aesthetic development and visual literacy, but also skills related to critical thinking, communication and tolerance of ambiguity (Hailey et al., 2015), which are essential for reflective engineers. Since its creation a few decades ago, VTS is also proving valuable in other fields, such as in medical and nursing schools to enhance students' skills of observation and diagnosis (Reilly et al., 2005; Hailey et al., 2015) and in other areas of higher education (Yenawine & Miller, 2014) such as for communicating science research findings to others (Hancock 2016). Here we extend the use of VTS into engineering education.

Pilot Course Offering (2017):

Our pilot course was offered in 2017 as a 1-credit seminar that met weekly for about two hours. A typical class period is summarized in the following outline:

1) VTS Exercises (15 min., starting Week 6):
   Instructor facilitated a class discussion of a selected image or two (building on an initial VTS workshop of Week 5).

2) Introduction & Activity (50 min.):
   Instructor or guest speaker introduced a topic, laid out a dilemma/issue/conflict, and (maybe) made recommendations.
   Then, students read a relevant article or watched a relevant video, reflected on what they read or watched, and jotted down some notes/ideas for an essay.

3) Discussion (50 min.):
   Students discussed the issue in small groups and/or all together as a class.

4) Writing (50 min, after class, either in the classroom or elsewhere if they wished):
   Students wrote an essay that explained their understanding of the dilemma, conflict, or problem, discussed the key technical, social, political, economic, cultural, environmental, and ethical issues, and made recommendations.

Thus, typical classes for the 2017 pilot offering involved the introduction of topic, an activity, group discussion, and unstructured time for writing/reflecting. Themes included:

- Situational/ethical dilemmas (e.g., recycling of e-waste, chronic kidney disease of unknown etiology)
- Technical Rationality / Reflection-in-action (see Schön 1983)
- Agricultural issues (e.g., water scarcity/quality, soil erosion)
- Climate change and grand challenges
- Visual Thinking Strategies (VTS)
- Ecocriticism

The arts- and humanities-based activities associated with these themes used in 2017 included:

- writing an autobiography
- participating in a VTS mini-workshop and practicing VTS exercises in class
- writing weekly reflection essays with a focus on either:
  a) the broader contextual implications of the week's topic or
  b) the content, activity and/or educational material itself
- creating mid-term and final portfolio assignments based on the weekly essays
- watching/discussing a documentary video about an anthropogenic ecological disaster
- visiting the campus museum and taking a walking tour of campus art
- reading/discussing a novel that had a strong environmental justice theme

Second Course Offering (2019):

We offered the course a second time in 2019 as a 3-credit "special topics" course that met weekly for nearly three hours. A typical class period is summarized in the following outline:

1) Part A:
   Introduction (30 min.): Instructor or guest speaker introduced a topic or issue
   Activity (30 min.): Students read a relevant article, watched a relevant video, or engaged in an educational activity
   Discussion (20 min.): Students discussed the topic or issue in small groups and/or all together as a class
2) Break (10 min.)
3) Part B (80 min.)
   Same as Part A with a new topic [OR] Continue from Part A

Thus, typical classes for the 2019 course involved the introduction of a topic, a related activity, a group discussion, a break, and then a new topic or activity; however, sometimes a guest speaker or activity would take the entire class period. Themes included:

- Reflective Engineering
- Bildung (holistic development of the self in relation to the world – see Kim, Morrison, & Ramzinski, 2019)

- Engineering Meets Art (a collaborative group art project)
- Art & Creativity
- Visual Thinking Strategies (VTS)
- Narrative & Communication
- Visual Thinking in Engineering
- Ecocriticism

The arts- and humanities-based activities associated with these themes included:

- writing an autobiography, creating a companion art piece, and presenting them to the class as a form of Bildung
- participating in a 5-week group project with graduate students from the school of art to create collaborative artwork and write group artists' statements
- writing weekly reflection essays with a focus on either:
  a) one's current conceptualization of the relationship between an engineer, the environment, and a community or
  b) the content, activity and/or educational material itself
- participating in a VTS mini-workshop and practicing VTS exercises in class
- reading/discussing one of two novels that had strong environmental justice themes

For the 2019 instantiation of the course, the initial VTS mini-workshop was held during Week 10 after spring break and the subsequent VTS practice sessions were longer in duration and fewer in number, concentrated in Part B of each class period for a few weeks following the workshop.

Class Participants

The course was offered through the civil, environmental, & construction engineering department as an elective open to all graduate students of any major. To date, only engineering graduate students have enrolled: 12 from the 2017 pilot course and 9 from the 2019 offering.[1] Of the 19 students who completed both the pre- and post-course surveys, 12 were women, 7 were men, and about half were international students. Majors were primarily environmental engineering (9) with some civil engineering (4) and chemical engineering (2). Twelve were doctoral students (both women and men), and 7 were master's students. Student majors, degree programs, and genders are summarized in Table 1.

[1] Current enrollment for the Spring 2020 course offering has been capped at 20 students.

Table 1: Student Demographics

Engineering Major	Female	Male	**Total**
Civil	1	3	**4**
Chemical	0	2	**2**
Environmental	11	2	**13**
Total	**12**	**7**	**19**
Degree Program			
Ph.D.	7	5	**12**
M.S.	1	1	**2**
MEV*	4	1	**5**
Total	**12**	**7**	**19**

* MEV is a 5-Year "freshman-to-master's degree" program in Environmental Engineering. MEV students in our course are all in their 4th or 5th years.

Reflective Engineering

Before we attempt answers to our research questions, it is helpful to consider what we mean by reflection, its outcomes, and the context in which reflection is conducted. Scholarly interest on the topic of reflection in engineering education has increased significantly in recent years (Sepp et al. 2015; Kim, Campbell, et al., 2019) due in part to the efforts of the Consortium to Promote Reflection in Engineering Education (CPREE, see www.cpree.uw.edu). In the context of reflecting on experiences broadly, reflection has been defined as "an intentional and dialectical thinking process where an individual revisits features of an experience with which he/she is aware and uses one or more lenses in order to assign meaning(s) to the experience that can guide future action (and thus future experience)" (Turns et al. 2014). This definition is consistent with our conception of skills and habits needed by reflective engineers, though we think it important to emphasize extending the temporal view to include not only the past, but also the present. Schön's (1983) idea of "reflection-in-action" captures this well because it draws attention to an active and ongoing thought process that is mindful of actions as they are being performed, possibly over an extended period of time (e.g., the "action-present," which is a variable period of time that depends on the context and might take seconds, minutes, hours, days, weeks, or even months depending on the decisions being made and the project undertaken) (p. 62).

Our conceptual framework derives in part from Schön's (1983) ideas about the limitations of Technical Rationality (positivism) and the importance of Reflection-in-Action (praxis). However, we also acknowledge related ideas from the Reflective Judgement model of King &

Kitchner (1994 & 2004), namely the ideas that (a) some problems are not well posed and can never be solved with absolute certainty, (b) abilities must be developed to critically evaluate available evidence to work toward an understanding of the problem and the reasons that it is not well-posed, and (c) understandings can change and one must adapt as the available evidence improves or changes.

In an effort to operationalize reflection and its outcomes for the reflective engineer, we created a survey comprised primarily of items from validated scales found in the literature. The pilot version of the survey covered 14 variables or psychological constructs comprised of 92 Liker-type items and the second version added 2 more variables/constructs comprised of 24 items, bringing the total up to 16 variables/constructs comprised and 116 survey items. These items were sorted randomly in tables and printed on paper for completion by the students on the first day of class and again at the last day of class 16-weeks later. The survey took about 20 to 30 minutes for most students to complete. For the purpose of analysis and reporting, the variables/constructs are organized by grouping them into three categories:

- Aspects of Reflective Thinking: this is a first-step toward operationalizing of some of the multiple dimension of reflection, such as predispositions, habits of mind, and behaviors that facilitate reflective ways of thinking and doing. There were 8 variables/constructs in this category including: Critical Openness, Engagement in Self-reflection, Insight, Need for Cognition, Need for Self-reflection, Reflection, Reflective Behavior, and Reflective Scepticism.
- Potential Outcomes of Reflective Thinking: this is a selection of variables/constructs that suggest what it means and what it takes to be a reflective engineer, such as skills, traits, and/or characteristics that reflection and/or interactions with arts & humanities might reasonably be expected to influence. There were 5 variables/constructs in this category including: Contextual Competence, Integrity, Interdisciplinary Skills, Ambiguity Tolerance, and Creativity.
- Related Perceptions of Engineering: this is a collection of ad hoc survey questions we devised to explore how students perceive engineering with respect to ambiguity, problem solving, and reflection (which are possibly inter-related). There were 3 variables/ constructs in this category including: Ambiguity in Engineering, Problem Solving in Engineering, and Reflection in Engineering. However, these 3 variables/constructs will not be discussed in this paper in the interest of brevity and because their item counts are low and their psychometrics have not been tested.

These variables/constructs with their respective item counts and sources are summarized in Table 2 and are described in further detail below.

Table 2: Summary of Survey Variables/Constructs

Category	Variable/Construct	# of items	Source
Aspects of Reflective Thinking	Insight	8	Self-Reflection & Insight Scale (SRIS) by Grant et al. (2002)
	Engagement in Self-Reflection	6	
	Need for Self-Reflection	6	
	Need for Cognition	18	Need for Cognition Scale (NCS) short form by Cacioppo et al. (1984)
	Critical Openness	7	Critical Thinking Disposition Scale (CTDS) by Sosu (2013)
	Reflective Skepticism	4	
	Reflective Behavior	2	Interdisciplinary Competence Scale (ICS) by Lattuca et al. (2013)
	Reflection*	4	Reflective Thinking Scale (RTS) by Kember et al. (2000)
Potential Outcomes of Reflective Thinking	Contextual Competence	4	Contextual Competence Scale (CCS) by Ro et al. (2015)
	Interdisciplinary Skills	8	Interdisciplinary Competence Scale (ICS) by Lattuca et al. (2013)
	Integrity	18	The Integrity Scale (IS) by Schlenker (2008)
	Ambiguity Tolerance*	20	Ambiguity Tolerance Scale (ATS) revised by Mac Donald (1970)
	Creativity	6	Ad-hoc scale: validity & reliability not tested
Related Perceptions of Engineering	Ambiguity in Engineering	2	Ad-hoc scale: validity & reliability not tested
	Problem Solving in Engineering	2	
	Reflection in Engineering	1	

* These two scales were added for the 2019 course offering.

The variables/constructs under the Aspects of Reflective Thinking category of Table 2 provide a means of assessing reflective thinking directly. Each is described in detail as follows (adapted from our previous work in Campbell et al., 2018):

- Insight, Engagement in Self-Reflection, and Need for Self-Reflection are the three factors that comprise Grant et al.'s (2002) Self-Reflection & Insight Scale. They define Insight as “the clarity of understanding of one’s thoughts, feelings and behavior…” and they define Self-Reflection as “the inspection and evaluation of one’s thoughts, feelings and behavior.” These constructs “are metacognitive factors central to the process of purposeful, directed change …”

- Need for Cognition is from Cacioppo et al.’s (1984) Need for Cognition Scale short form, which “refers to an individual’s tendency to engage in and enjoy effortful cognitive endeavors.” Furthermore, they write “[r]esearch on need for cognition suggests that this characteristic is predictive of the manner in which people deal with tasks and social information…”
- Critical Openness and Reflective Scepticism are the two factors that comprise Sosu’s (2013) Critical Thinking Disposition Scale. He writes: “The Critical Openness subscale reflects the tendency to be actively open to new ideas, critical in evaluating these ideas and modifying ones thinking in light of convincing evidence.” Reflective Scepticism on the other hand, “conveys the tendency to learn from one’s past experiences and be questioning of evidence.” Furthermore, “[t]he two dimensions appear to capture the perspectives inherent in the definition of critical thinking, and the taxonomies of thinking dispositions…”.
- Reflective Behavior is a sub-scale of the Interdisciplinary Competence Scale by Lattuca et al. (2013). They suggest that “[r]eflection occurs when evaluating information sources or evaluating complex problems or controversial issues …[and it] involves the ability to reflect on one’s biases and the choices one makes when defining problems or interests, building understanding, problem solving…”
- Reflection is a sub-scale[2] of the Reflective Thinking Scale by Kember et al. (2000), who define reflection using ideas from the fields of education and psychology including those of Dewey, Boud, Mezirow, Boyd & Fales, and Schön. A synthesis of these ideas is better summarized by examining the survey items themselves, which incorporate the ideas of comparison and improvement. The first involves questioning how other do something, the second, third, and fourth involve thinking over one’s own actions and experiences in order to do better.

The variables/constructs under the Potential Outcomes of Reflective Thinking category of Table 2 provide a means of assessing some of the broader dimensions of what it means to be a reflective engineer. Each is described in detail as follows (adapted from our previous work in Campbell et al., 2018):

- Contextual Competence from the Contextual Competence Scale by Ro et al. (2015, 2012) aims to capture “an engineer’s ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions.”

---

[2] Note: Of the four sub-scales that comprise the Reflective Thinking Scale, we used only one (Reflection) because the others were either not amenable to pre/post assessment or were designed for more traditional lecture-based courses (e.g., with exams and homework problems) and therefore of questionable relevance to our discussion- and writing-based course. However, we may consider adapting and adding them in the future

- Interdisciplinary Skills is a sub-scale[3] of the Interdisciplinary Competence Scale by Lattuca et al. (2013) that aims to assess “students’ perceptions of their abilities to think about and use different disciplinary perspectives in solving interdisciplinary problems or to make connections across academic fields.”
- Integrity from the Integrity Scale by [17] is “principled commitment … steadfast adherence to a strict moral or ethical code … synonyms include being honest, upright, and incorruptible. … focuses on the strength of people’s claims of being principled (as opposed to expedient), and items assess the inherent value of principled conduct, the steadfast commitment to principles despite costs or temptations, and the unwillingness to rationalize violations of principles.”
- Ambiguity Tolerance[4] is from the revised Ambiguity Tolerance Scale (ATS) by Mac Donald (1970), who pointed out a lack of consensus on the definition of ambiguity in the literature, but wrote that “[i]ntolerance of ambiguity may be viewed as a general tendency to perceive ambiguous material or situations as threatening … Conversely, tolerance of ambiguity implies that contact with ambiguity is desirable … It is the impression of the author that persons having high tolerance of ambiguity (a) seek out ambiguity, (b) enjoy ambiguity, and (c) excel in the performance of ambiguous tasks.”
- Creativity is from an ad-hoc scale we created to explore student perceptions of creativity, both in engineering and in general. For example, some items probed whether student thought engineers were creative, whether they were creative themselves, or whether creativity was useful to engineers. Although validity & reliability have not been tested, we thought it worth exploring given the use of the creative arts and humanities in the course.

The variables/constructs under the Related Perceptions of Engineering category of Table 2 will not be detailed in this paper in the interest of brevity and because their psychometrics have not been tested and their item counts are low.

Methods

In this paper, we focus on the pre/post Likert-type survey data. However, we note here that this is only a fraction of the data we are collecting and analyzing for our larger mixed-methods study (see the last paragraph of the Introduction for further details). All data has been collected with the approval of our university’s human subjects division.

[3] Note: We used only two of the three sub-scales that comprise the Interdisciplinary Competence Scale because the third sub-scale (Recognizing Disciplinary Perspectives) was initially found to be of questionable relevance to the context of our course and its objectives. However, we may consider adding it in the future.

[4] This variable/construct was added for the 2019 course offering. The idea for exploring ambiguity tolerance came from the literature on Visual Thinking Strategies (VTS), which suggests that practicing VTS can increase one’s tolerance and appreciation of ambiguity (see Klugman, Peel, & Beckmann-Mendez, 2011). Our experience with VTS was consistent with this and we recognized it as an important component of what it takes to be a reflective engineer because real-world engineering problems are often poorly defined and replete with ambiguity.

To perform the statistical analysis presented here, pre- and post-course responses to all the survey items comprising each of the above measures were entered into an Excel spreadsheet. Reverse-coded items were adjusted accordingly and average scores across all items within each variable/construct were computed for each participant. These were then aggregated (averaged) across all participants to compute a pre/post pair of number for each variable/construct. The pre to post changes in these averages were then tested for statistical significance using a 2-tailed, paired *t*-Test, which is appropriate for paired responses with a small sample size (though we acknowledge some concerns with the normality assumption). Effect sizes were computed using the Cohen's *d* measure.

Findings & Discussion

This section presents findings from the analysis of the pre/post Likert-type survey responses. For all statistics reported, the sample size was $n = 19$ with the exception of Reflection and Ambiguity Tolerance, for which $n = 9$ since these were added for the 2019 course offering. Six-point scales were used for all measures with the exception of Contextual Competence, which employed its own 5-point scale.

Table 3 summarizes the findings for both categories of our measures that help us operationalize reflective thinking (i.e., Aspects of Reflective Thinking, which assess reflective thinking directly, and Potential Outcomes of Reflective Thinking, which are dimensions of what it means and what it takes to be a reflective engineer. Of note here are the highlighted rows indicating the statistically significant changes in Insight ($p < 0.02$, $d > 0.3$) and Contextual Competence ($p < 0.001$, $d > 0.8$). Additionally, the italicized rows indicate two variables/constructs that can be considered approaching statistical significance, namely Reflective Scepticism ($p < 0.1$, $d > 0.3$) and Interdisciplinary Skills ($p < 0.3$, $d > 0.25$). Some of the data behind this table are presented graphically in Figure 1 and Figure 2, which depict the aggregate pre/post survey averages and deltas for the Aspects of Reflective Thinking category and the Potential Outcomes of Reflective Thinking category, respectively.

Figure 3 and Figure 4 provide deeper views of the data, showing boxplots for the Aspects of Reflective Thinking category and the Potential Outcomes of Reflective Thinking category, respectively. As these figures show for the pre-surveys, the range of responses from lowest to highest was skewed toward the top of the scale ranges, suggesting these students started off high in many of these measures and did not have much room for growth. In fact, of the 14 measures presented, only Insight, Contextual Competence, and Ambiguity Tolerance started off with pretest averages below two-thirds of their respective maximum scale values (6-, 5-, and 6-points, respectively).

The fact that Ambiguity Tolerance showed no measurable change despite the apparent room for improvement and the expectation VTS might affect this is curious. There are several possible reasons why we did not see the anticipated change. The first is of course due to the low sample size for this variable/construct ($n = 9$) since it was added for the 2019 offering only. The second reason is the possibility that our use of VTS was too limited and/or too late in the semester to produce a noticeable effect. In the 2017 offering, we held the initial VTS workshop during week 5 and then practiced VTS in the classroom in 8 of the remaining class meetings. In the 2019 offering, we held the workshop during week 10 and practiced VTS in only 2 or 3 of the remaining class meetings, albeit for longer time periods. With data on this variable/construct from only one course offering we can only speculate. A third possible reason could be related to problems with items in the Ambiguity Tolerance Scale that were observed. For example, a few questions depend on knowledge that may not be equally shared by students, such as “I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner.” This requires knowledge of gambling that may be unknown to some students and may be especially challenging to those for whom English is not a native language. Also, complex words like “impressionistic” and “unambiguous” that appeared in this scale may be unclear even to native speakers of English and because of the quiet atmosphere when the surveys are administered, students would be unlikely to ask and risk revealing their ignorance to others. It could also be that the Ambiguity Tolerance Scale is not contextualized well enough our course and/or for engineering students.

Table 3: Pre/Post Likert-type Survey Results (n = 19 unless otherwise noted)

Category	**Variable/Construct**	**Change in Average**	***p*-Value (*t*-Test, 2 tailed, paired)**	**Effect Size (Cohen's *d*)**
Aspects of Reflective Thinking	Insight	0.33	0.015	0.327
	Engagement in Self-reflection	0.11	0.403	
	Need for Self-reflection	-0.03	0.867	
	Need for Cognition	0.03	0.712	
	Critical Openness	0.01	0.923	
	Reflective Scepticism	*0.18*	*0.084*	*0.314*
	Reflective Behavior	-0.04	0.851	
	Reflection (n=9)	0.11	0.447	
Potential Outcomes of Reflective Thinking	Contextual Competence†	0.54	4.7E-6	0.860
	Interdisciplinary Skills	*0.13*	*0.263*	*0.280*
	Integrity	0.09	0.259	
	Ambiguity Tolerance (n=9)	0.04	0.614	
	Creativity‡	0.07	0.483	

† 5-point scale ‡ Ad-hoc scale (validity and reliability not tested)

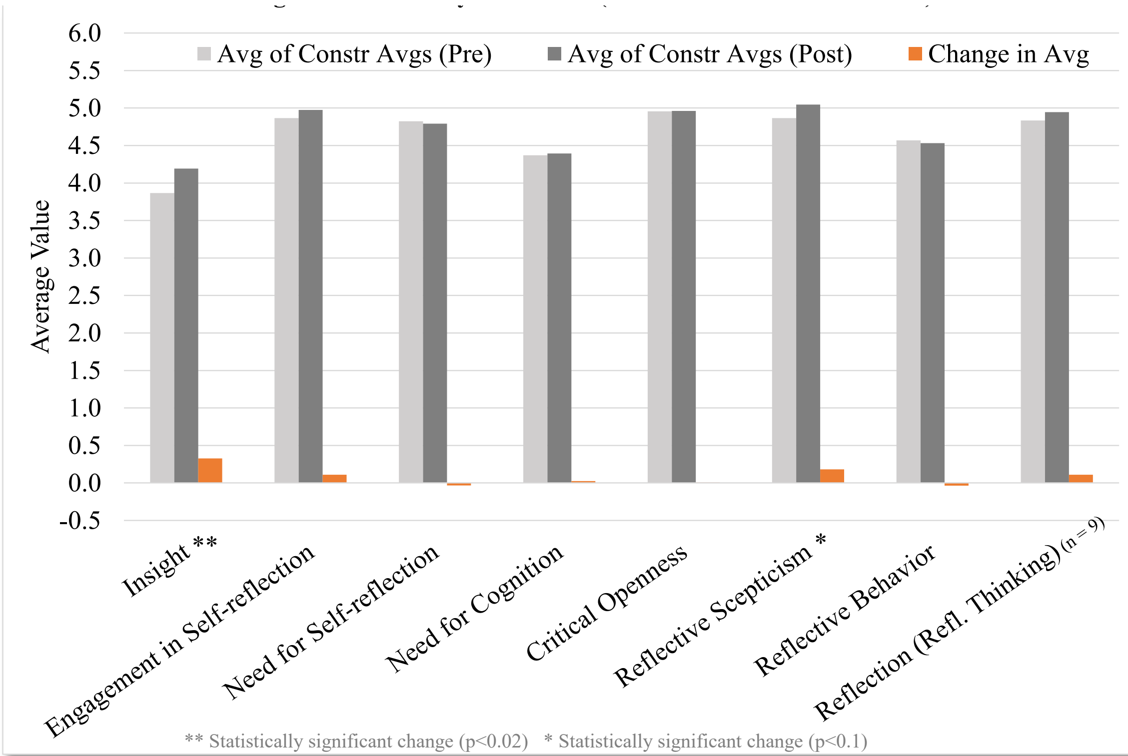

Figure 1: Aggregate pre/post survey averages & deltas: Aspects of Reflective Thinking

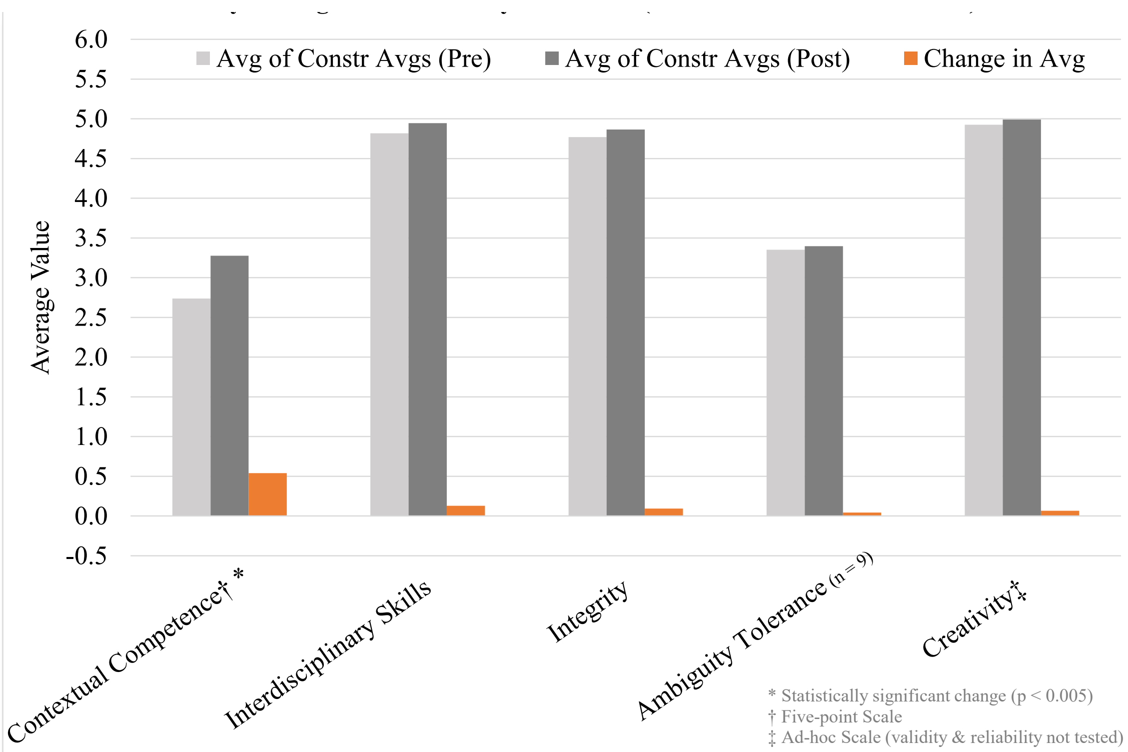

Figure 2: Aggregate pre/post survey averages & deltas: Potential Outcomes of Reflective Thinking

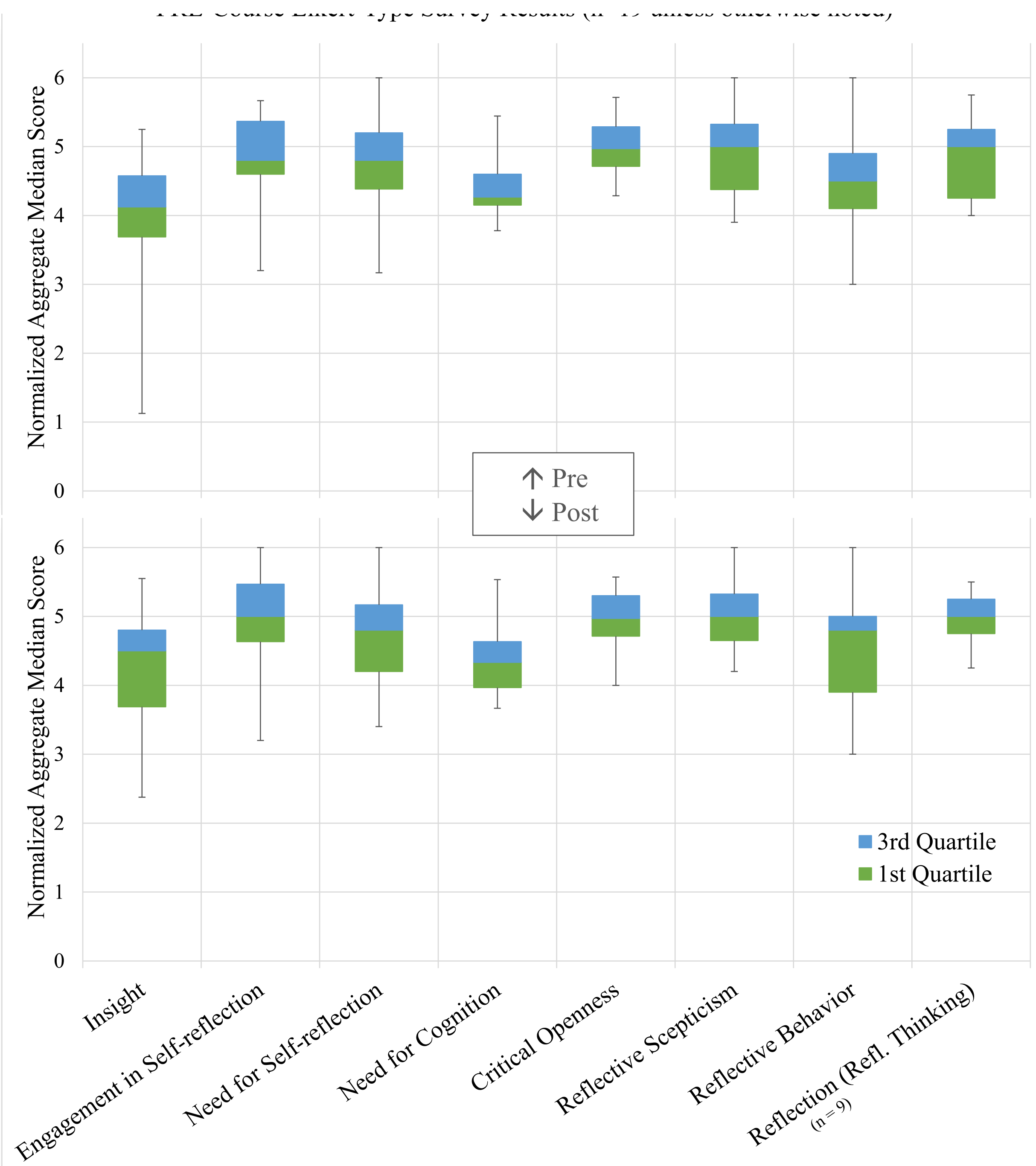

Figure 3: Boxplots of pre/post survey data: Aspects of Reflective Thinking

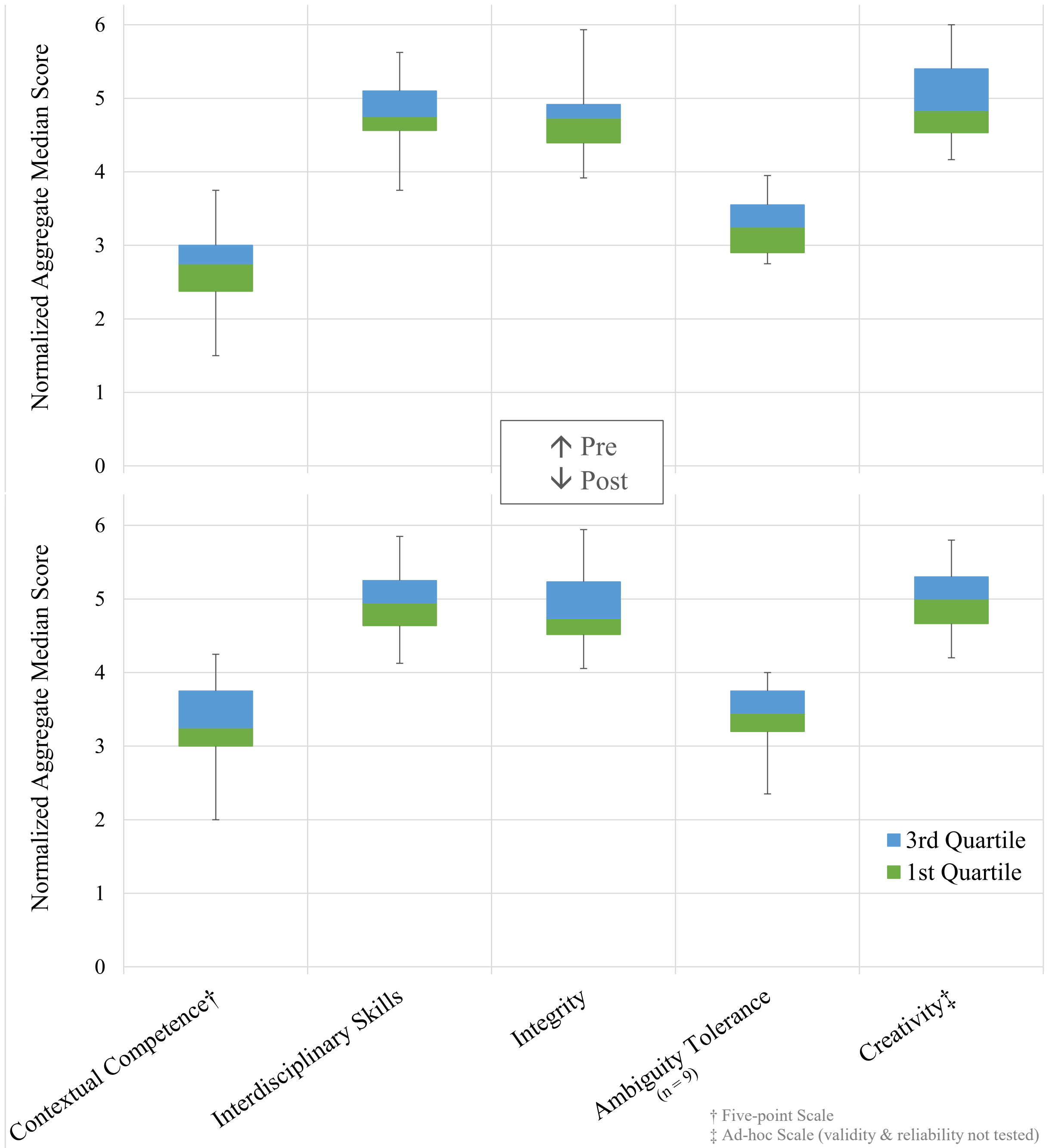

Figure 4: Boxplots of pre/post survey data: Potential Outcomes of Reflective Thinking

One limitation of this study is the relatively small sample size (*n* = 19 for most measures). To address this, we are offering the course again this year and have achieved an enrollment of 20 graduate students, which will effectively double our sample size by the time this work will be presented at the annual conference. Another limitation is the broad-brush effect of using a pre/post survey, which makes cause and effect difficult to pin down when so many different course activities and assignments are at play throughout the semester. To address this concern and gain focus on which aspects of the course might contribute to which measures of change, we are analyzing other data types and sources, such as student interviews that were conducted outside of the classroom and student writing samples that were collected in response to specific classroom interventions. Other limitations we should acknowledge are the potential effects of different instructor(s) and educational context, which will affect replicability and make consistency of findings across instructors, classrooms, and institutions difficult to achieve. These concerns are being addressed by ongoing qualitative and mixed-methods research that better communicates the important personal and contextual details necessary for successful adaptation by other instructors to their own educational contexts. Future work may also include offering the course with different primary instructors and/or at other institutions.

Nevertheless, the findings we report here are consistent with what we presented previously in Campbell et al. (2018) and lend support to the premise that engineering students can develop their capacity for reflection through arts- and humanities-based activities. We are finding measurable and significant increases in the self-reported abilities of engineering students to engage in reflective thinking as operationalized by:

a. Insight which is “the clarity of understanding of one’s thoughts, feelings and behavior” (Grant, Franklin, & Langford, 2002). In this case, we report statistical significance of $p < 0.02$ with a modest effect size of $d > 0.3$
b. Contextual Competence, a potential outcome of reflective thinking described as “an engineer’s ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions” (Ro et al. 2015). In this case we report statistical significance of $p < 0.001$ with a large effect size of $d > 0.8$
c. Reflective Scepticism: “the tendency to learn from one’s past experiences and be questioning of evidence” (Sosu, 2013). In this case we report it as approaching statistical significance ($p < 0.1$) with a modest effect size of $d > 0.3$

We believe each of these components (Insight, Reflective Skepticism, and Contextual Competence) are closely related to reflective thinking and show our course to be on the right track for reaching our goal of developing reflective engineers.

Conclusions

In this paper, we presented findings from two semesters implementing a newly designed graduate curriculum in civil/environmental engineering that integrates the arts and humanities to develop reflective engineers. This work has built on and extended the brief findings presented previously from the pilot offering of the course (see Campbell et al., 2018) by aggregating the pre/post survey data set with the second offering to bring the sample size up to 19 ($n = 19$). In this paper, we reported significant increases in measures of Insight and Contextual Competence as well as potential increases in several other self-report-type measures of reflection. These results begin to address our research question about the extent to which participation in arts- and humanities-based course activities might change the abilities of engineering students to engage in reflective thinking.

Our findings thus far have been encouraging, not only from these surveys, but from analyses of student writing and interviews reported elsewhere (see Kim, Campbell, et al., 2019; Kim et al., 2020; and Taraban et al., forthcoming). Additional survey findings from the course in progress at the time of this writing may be ready to share at the ASEE conference in June. Continued expansion and testing of additional materials and activities in subsequent iterations of the course via multi- and mixed-methods research is ongoing and will further guide our understanding of effective approaches to fostering reflective habits and skills in graduate engineering education via the arts and humanities.

Considering these findings and based on our experience, we call on faculty members in colleges of engineering to encourage their graduate students to take novel courses like this or otherwise support such integrative endeavors. If innovative coursework and curricula that go beyond expanding technical knowledge are to be successful and achieve higher enrollments, the buy-in and support of engineering faculty is greatly needed, especially in graduate education. We therefor invite you to join us in promoting such ventures to incorporate the arts and humanities in engineering and strive to develop habits, skills, and abilities for reflective thinking. As indicated in a recent consensus study report about integrating the arts and humanities with the sciences, engineering, and medicine in higher education (see National Academies of Science, Engineering, and Medicine, 2018) "further effort [should] be expeditiously exerted to develop and disseminate a variety of approaches to integrated education and … further research on the impact of such programs and courses on students [should] be supported and conducted." We look forward to the broad, interdisciplinary collaborations this will surely require.

Acknowledgement

This material is based upon work partially supported by the National Science Foundation under Grant No. 1806889. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Our sincere gratitude and appreciation to: Dr. Jill Hoffman from the Museum of Texas Tech University for her gracious assistance and support; Linda Duke from the Beach Museum of Art at Kansas State University for providing training on the VTS technique; Prof. Sangmi Yoo from the School of Art at Texas Tech University for her contributions to course development; Dr. Frank Donato from the Dept. of Psychological Sciences and Mr. David Robledo from the Dept. of English (Technical Communication & Rhetoric) for their contributions to course development; and our dedicated students for making this work possible, fruitful, and enjoyable.

References

Cacioppo, J. T., Petty, R. E., & Kao, C. F. (1984). The efficient assessment of Need for Cognition. *Journal of Personality Assessment, 48*(3), 306–307. https://doi.org/10.1207/s15327752jpa4803_13

Campbell, R. C., Reible, D. D., Taraban, R., & Kim, J.-H. (2018). Fostering Reflective Engineers: Outcomes of an Arts- and Humanities-Infused Graduate Course. In *Proceedings of the 2018 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC)* (p. 6). Albuquerque, NM, USA: IEEE. https://doi.org/10.1109/WEEF-GEDC.2018.8629714

Csavina, K., Nethken, C., & Carberry, A. (2016). Assessing student understanding of reflection in engineering education. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference*. New Orleans, LA, USA: ASEE. https://doi.org/10.18260/p.26306

Dewey, J. (1915/2001). *The School and Society*. Dover Publications.

Eisner, E. W. (2005). The role of the arts in cognition and curriculum. In E. Eisner (Ed.), *Reimagining Schools: The Selected Works of Elliot W. Eisner* (pp. 76–85). Routledge.

Grant, A. M., Franklin, J., & Langford, P. (2002). The Self-Reflection and Insight Scale: A new measure of private self-consciousness. *Social Behavior & Personality: An International Journal, 30*(8), 821–835. https://doi.org/10.2224/sbp.2002.30.8.821

Hailey, D., Miller, A., & Yenawine, P. (2015). Understanding Visual Literacy: The Visual Thinking Strategies Approach. In D. M. Baylen & A. D'Alba (Eds.), *Essentials of Teaching and Integrating Visual and Media Literacy* (pp. 49–73). Springer International Publishing. https://doi.org/10.1007/978-3-319-05837-5_3

Hancock, S. C. (2016, April 13). *Research communication program helps global food systems teams harness the power of visuals*. K-State Today. https://web.archive.org/web/20160420224333/https://www.k-state.edu/today/announcement.php?id=26764

Harlim, J., & Belski, I. (2013). Educating a reflective engineer: Learning from engineering experts. In C. Lemckert, G. Jenkins, & S. Lang-Lemckert (Eds.), *Proceedings of the 24th Annual Conference of the Australasian Association for Engineering Education*. Queensland, Australia: Griffith School of Engineering, Griffith University.

Kim, J.-H., Campbell, R. C., Nguyen, N. T. T., Taraban, R., Reible, D., & Na, C. (2019). Exploring Ways to Develop Reflective Engineers: Toward Phronesis-Centered Engineering Education. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference* (p. 21). Tampa, Florida, USA: ASEE. https://peer.asee.org/32819

Kim, J.-H., Morrison, J., & Ramzinski, E. (2019). Is Bildung possible in the classroom?: Autobiographical writing as philosophical exercise (askēsis) for developing one's Bildung. *Journal of Curriculum and Pedagogy*. https://doi.org/10.1080/15505170.2019.1581676

Kim, J.-H., Nguyen, N. T. T., Campbell, R. C., Taraban, R., Reible, D., Chongzheng, N., & Yoo, S. (2020). Would Eisner Be Happy with Us?: Developing Reflective Engineers through an Arts-Incorporated Engineering Graduate Curriculum (p. 5). Accepted for presentation at the 2020 American Educational Research Association (AERA) Annual Meeting, San Francisco, CA, USA: AERA.

King, P. M., & Kitchener, K. S. (1994). *Developing Reflective Judgment*. Jossey-Bass.

King, P. M., & Kitchener, K. S. (2004). Reflective Judgment: Theory and research on the development of epistemic assumptions through adulthood. *Educational Psychologist, 39(*1), 5–18. https://doi.org/10.1207/s15326985ep3901_2

Klugman, C. M., Peel, J., & Beckmann-Mendez, D. (2011). Art Rounds: Teaching Interprofessional Students Visual Thinking Strategies at One School. *Academic Medicine, 86*(10), 1266–1271. https://doi.org/10.1097/ACM.0b013e31822c1427

Lattuca, L. R., Knight, D., & Bergom, I. (2013). Developing a measure of Interdisciplinary Competence. *International Journal of Engineering Education, 29*(3), 726–739.

Mac Donald, Jr., A. P. (1970). Revised Scale for Ambiguity Tolerance: Reliability and Validity. *Psychological Reports, 26*(3), 791–798. https://doi.org/10.2466/pr0.1970.26.3.791

National Academies of Sciences, Engineering, and Medicine (NASEM) (2018). *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree*. The National Academies Press. https://doi.org/10.17226/24988

Reilly, J. M., Ring, J., & Duke, L. (2005). Visual Thinking Strategies: A New Role for Art in Medical Education. *Family Medicine, 37*(4), 250–252. https://www.stfm.org/familymedicine/vol37issue4/Reilly250

Ro, H. K., Merson, D., Lattuca, L. R., & Terenzini, P. T. (2015). Validity of the Contextual Competence Scale for engineering students. *Journal of Engineering Education, 104*(1),35–54. https://doi.org/10.1002/jee.20062

Ro, H. K., Lattuca, L. R., Merson, D., & Terenzini, P. T. (2012). Measuring engineering students' Contextual Competence. In *Proceedings of the ASEE Annual Conference*, San Antonio, TX, USA: ASEE. https://peer.asee.org/21677

Schlenker, B. R. (2008). Integrity and character: Implications of principled and expedient ethical ideologies. *Journal of Social & Clinical Psychology, 27*(10), 1078–1125. https://doi.org/10.1521/jscp.2008.27.10.1078

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. Basic Books Inc.

Sepp, L., Orand, M., Turns, J., Thomas, L., Sattler, B., & Atman, C. (2015). On an upward trend: Reflection in engineering education. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference*, Seattle, WA, USA: ASEE. https://doi.org/10.18260/p.24533

Sosu, E. M. (2013). The development and psychometric validation of a Critical Thinking Disposition Scale. *Thinking Skills and Creativity, 9*, 107–119. https://doi.org/10.1016/j.tsc.2012.09.002

Taraban, R., Donato, F., Robledo, D., Campbell, R. C., Kim, J.-H., Reible, D., & Na C. (forthcoming). Engineering, the Environment, and the Community through Art and Narrative. Accepted for presentation and publication at the 2020 American Society for Engineering Education (ASEE) Annual Conference. Montreal, Ontario, Canada: ASEE.

Turns, J. A., Sattler, B., Yasuhara, K., Borgford-Parnell, J. L., & Atman, C. J. (2014). Integrating reflection into engineering education. In *Proceedings of the ASEE Annual Conference*, Indianapolis, IN, USA: ASEE. https://peer.asee.org/20668

Yenawine, P., & Miller, A. (2014). Visual thinking, images, and learning in college. *About Campus, 19*(4), 2-8. https://doi.org/10.1002/abc.21162