# Fostering Reflective Engineers:

## Outcomes of an Arts- and Humanities-Infused Graduate Course

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***Abstract*—Engineering education traditionally focuses on technical content and problem-solving, leaving little room in the curriculum to examine broader environmental and socio-technical impacts of engineering work. However, if engineers wish to have intentional, positive influences on these broader impacts, skills for reflective thinking and ethical decision-making are essential. The arts and humanities can provide important and often neglected perspectives for engineers in developing such skills. In a recent seminar course for civil/environmental engineers, we explored ways of developing these skills through activities including Visual Thinking Strategies (VTS), in-class readings & discussions, essay writing, and portfolio assignments. In this paper, we present selected findings from this experimental course. While the class was small, comprised of a dozen graduate students, results were encouraging. For example, findings from qualitative thematic analysis of pre- and post-course essays showed an increase in recognition of the importance of breadth of knowledge and/or perspective. Similarly, pre-post Likert-type survey results showed a statistically significant increase ($p<0.005$, $d=1$, $n=10$) in Contextual Competence, a self-reported measure of ability to anticipate and understand the impacts and constraints of broader contexts on engineering solutions. These findings are preliminary but suggest the course helped students develop capacity for reflection through arts- and humanities-based activities.**

***Keywords*—reflection; ethics; arts; humanities; social justice; context; contextual competence**

## I. Introduction

The theme of this conference is Peace Engineering, defined as “the application of science and engineering principles to promote and support peace” and which “envisions and works towards a world where prosperity, sustainability, social equity, entrepreneurship, transparency, community voice and engagement, and a culture of quality thrive.”[1] However, such a noble endeavor can only be successful if engineers are able to understand and account for the broader environmental and socio-technical forces that are shaping both themselves and the world they wish to improve. Engineering education has traditionally not placed enough emphasis on raising awareness of these considerations, much less on developing the knowledge and skills necessary to meaningfully integrate them in engineering work.

To address this weakness, we (an interdisciplinary team from engineering, psychology, and education) have created an “experimental” curriculum that aims to promote reflective inquiry and practice among engineering students to foster their phronesis (i.e., ethical judgment / practical wisdom). The curriculum incorporates the arts and humanities to provide important and often-neglected perspectives to aid engineers in developing skills for reflective thinking and ethical decision-making. Phronesis is an essential attribute for peace engineers who wish to meaningfully address any of the issues mentioned above (e.g., prosperity, sustainability, social equity, transparency, etc.) and ensure their influence is both intentional and positive. Courses and curricula like what we propose can contribute to moving engineering students and the profession towards a reflective way of thinking that gives more attention to peace and those elements necessary for promoting and sustaining it.

In this work, we begin to assess the effects of the curriculum we are developing, as implemented in the pilot offering of a recent graduate-level engineering course. Our overarching objective is to explore how the arts and humanities might help engineers become more reflective thinkers who have greater awareness of and sensitivity to the broader context of societal well-being and sustainability. Under this objective, we pose the following research questions:

*RQ1: In what qualitatively different ways might engineering students’ thinking change after participation in arts- and humanities-based course activities designed to develop reflective reasoning?*

*RQ2: To what extent might participation in arts- and humanities-based course activities change the abilities of engineering students to engage in reflective reasoning?*

### A. Description of Pilot Course

To begin answering these questions, we conducted mixed-methods research on a one-semester pilot offering of a graduate-level engineering course. This 1-credit seminar enrolled 12 graduate students majoring in civil and environmental engineering at the master’s and doctoral levels. Of those who completed both the pre- and post-course surveys, 7 students were women and 3 were men, and half were international students. The course met weekly for about 90 minutes, during which time we typically introduced a topic with a brief talk, video, or guest speaker, 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.[2] Other arts- and humanities-based activities we

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[1] See https://weef-gedc2018.org & www.ifees.net/peace-engineering-i

[2] See https://vtshome.org or [1]. Also note that VTS directly promotes communication and cultural understanding, which are essential components of any peace-building endeavor.

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.

### *B. Literature Review*

The topic of reflection has seen considerable growth in engineering education conferences in recent years [2], and the Consortium for the Promotion of Reflection in Engineering Education[3] has been actively promoting it. Reference [3] explored reflecting on experiences broadly, defining reflection in that context 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)."

Some empirical research has been done to assess how engineering students conceptualize reflection broadly. For example, [4] explored how second- and fourth-year undergraduate engineering students at a school in the southwestern United States understood reflection in the context of their design courses. They asked students in large project-based design courses how they defined reflection and found that most "saw reflection as an opportunity to look back at what they have done." Some also viewed reflection as impacting future actions. They also found that most student associated reflection with positive actions rather than with mistakes and failures.

This last finding appears to diverge from the findings of [5], who compared novice engineers (e.g., students and recent graduates with 5 or fewer years of experience) with expert engineers (e.g., practicing engineers with 6 or more years of experience) in Australia. They found that novice engineers were "likely to reflect only when mistakes are made," while expert engineers were "more likely to reflect continuously when they resolve problems." One might speculate that this discrepancy between novices could be due to a disconnect between professed values and action in practice, and/or perhaps it is evidence of a cultural difference.

In our research, we contribute to expanding the literature with a view of graduate students, and we explore conceptions and assessment of reflection in the context of engineering practice. As a first step toward answering our research questions, it is helpful to consider what we mean by reflection, its outcomes, and the context in which it is conducted.

## II. METHODS

We employ a mixed-methods approach [6]. As part of an iterative, multi-phase design, this paper represents a convergent parallel design in which both quantitative and qualitative data were collected and analyzed separately before relating them for interpretation. It aims to be primarily a qualitative study with quantitative methods used in a secondary role.

### *A. Conceptual Framework*

Our conceptual framework derives from the ideas of Technical Rationality (positivism) and Reflection-in-Action (praxis) from [7], as well as ideas from [8] and [9], 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.

### *B. Data Collection Instruments*

We collected data with the approval of our university's human subjects division under the exempt category for research conducted in established educational settings. Our data included hand-written responses to pre- and post-course essay questions and Likert-type surveys[4], and type-written essays including an autobiography, weekly essays about readings and discussion topics, a mid-term portfolio and a final portfolio comprised of annotated highlights of all course-work completed. In the interest of brevity, only the essay and survey questions discussed in this paper will be described below.

Our pre-course essay was comprised of four questions, the first of which was:

*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?*

The objective of this question and subsequent analysis of responses was to capture the different ways in which the students defined reflection in the context of engineering practice and to understand their conceptions of a reflective engineer. Knowing where students are in their understanding is useful in developing course and curricular materials having an appropriate level of challenge/difficulty, complexity, and effort and informs our ongoing curricular development. Also, by asking the same questions both pre- and post-course, we gain insight into possible changes in that understanding as brought about by the course itself, thus it can function as assessment and help to answer RQ1.

Our pre-course Likert-type survey was comprised of fourteen different variables/constructs, including the following: Contextual Competence, Critical Openness, Engagement in Self-reflection, Insight, Integrity, Interdisciplinary Skills, Need for Cognition, Need for Self-reflection, Reflective Behavior, and Reflective Scepticism, The survey items comprising these ten constructs were obtained from validated surveys published in the literature and are described further in the next section. Four additional constructs were also included in the surveys (Ambiguity, Creativity, Problem Solving, and Reflection in Engineering), but as these were ad hoc questions for which validation was not attempted they have been omitted from this analysis due to length limitations.

### *C. Assessment Approaches*

The operationalization and assessment approaches we have used can be divided into two types: assessing reflective thinking directly, and assessing potential outcomes of reflective thinking. Our structured essay question prompts implicitly encouraged responses from both types, and our Likert-type survey questions explicitly assessed both types.

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[3] See www.cpree.uw.edu

[4] Students wrote responses to the pre- and post- course essay questions prior to completing the Likert-type surveys.

*1) Essay Analysis Methods*

In this sub-section, we briefly describe the method employed to analyze the pre- and post-course essay data. First, the hand-written essays were transcribed by the lead author into text files. The contents of these files were checked against the originals and then used to compile a single spreadsheet file containing all the responses. This spreadsheet was then imported into a qualitative data analysis software program called Quirkos[5] which includes provisions for handling structured questions. The responses to the first essay question were read in Quirkos for each pair of essays (pre and post) for each student and inductively coded for themes observed in the data as identified by the lead author.

The application and refinement of codes was an iterative process in which code names, themes, and definitions were frequently compared with the data and with each other and adjusted as needed. Codes were applied to passages of varying length based on semantic units (i.e., units of meaning sometimes sentences or parts of sentences and sometimes entire paragraphs). Multiple codes were often applied to the same passages if they contained multiple ideas. Though not exact, the 6-step process of thematic analysis described by [10] provides a reasonable summary of the process used, though we have used a slightly different terminology (e.g., "categories" instead of "level 2 themes").[6]

*2) Survey Analysis Methods*

In this section, we introduce the constructs used in our pre-post survey and then briefly describe our statistical analyses. For direct assessment of reflective thinking, our survey included the following constructs:

- "Engagement in Self-reflection", "Insight", and "Need for Self-reflection" from the Self-Reflection & Insight Scale [11]. Self-Reflection is defined as "the inspection and evaluation of one's thoughts, feelings and behavior" whereas Insight is defined as "the clarity of understanding of one's thoughts, feelings and behavior…" These constructs "are metacognitive factors central to the process of purposeful, directed change …"
- "Need for Cognition" from the Need for Cognition Scale [12], which "refers to an individual's tendency to engage in and enjoy effortful cognitive endeavors. Research on need for cognition suggests that this characteristic is predictive of the manner in which people deal with tasks and social information…"
- "Reflective Behavior" from the Interdisciplinary Competence Scale [13], who indicate "[r]eflection occurs when evaluating information sources or evaluating complex problems or controversial issues … involves the ability to reflect on one's biases and the choices one makes when defining problems or interests, building understanding, problem solving…"
- "Reflective Scepticism" from the Critical Thinking Disposition Scale [14], which "conveys the tendency to learn from one's past experiences and be questioning of evidence"

For potential <u>outcomes</u> of reflective thinking, our survey incorporated the following constructs:

- "Contextual Competence" from the Contextual Competence Scale [15], [16], which 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."
- "Critical Openness" from the Critical Thinking Disposition Scale [14], which "reflects the tendency to be actively open to new ideas, critical in evaluating these ideas and modifying one[']s thinking in light of convincing evidence."
- "Integrity" from the Integrity Scale by [17], which 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."
- "Interdisciplinary Skills" from the Interdisciplinary Competence Scale [13], which 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."

Pre- and post-course responses to the survey items comprising each of the above constructs were entered into an Excel spreadsheet. Reverse-coded items were adjusted accordingly and average scores across all items in each construct were computed across all participants. 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. Effect sizes were computed using the Cohen's *d* measure.

## III. Findings

This section describes the findings from analysis of the essays and Likert-type surveys.[7]

### A. Essay Findings

Thematic analysis of student responses to the first essay prompt (i.e., the meaning of reflection in the context of engineering practice or what it means to be a reflective engineer) generated four major categories of themes: Breadth, Depth, Metacognition, and Time. Each of these is briefly described below. This will enable us to address RQ1 regarding qualitative changes student thinking.

*1) Breadth Category Findings*

The Breadth category is comprised of themes showing awareness of the need for breadth of knowledge or perspective as an element of reflective engineering. For example, the most prevalent theme "Reflection as broad perspective" (2 pre- and 6 post-course essays) was comprised of passages indicating that reflection in engineering means taking a broad perspective on the work. Keywords/phrases included: *all aspects/factors*, *big picture*, *broad vision/scope*, *global understanding*, *economic/ social/cultural effects*, *surrounding issues*, *unrelated knowledge*, *knowledge of other fields*, and *working with non-*

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[5] See www.quirkos.com

[6] Note that while thematic analysis was performed carefully and systematically, its purpose was to summarize and describe the data, not to generate numbers for statistical analysis. Numerical counts are provided in the findings for ancillary, informational purposes only.

[7] It is worth noting here that publication requirements can hinder the reporting of qualitative and mixed-methods research, especially that requiring detailed description. For example, the length restrictions imposed on this paper (6-pages) severely limits reporting of the analysis performed on the essays and forces an abbreviated presentation of its findings.

*like-minded others*. A representative quote from this theme is the following from the pre-course essay of Student 12:

> *"To me, reflection in engineering means taking time to look at the big picture of how your solutions to engineering problems will impact other environments and people."* (1)

Other themes in this category, in order of prevalence were: "Reflection as considering impacts/implications" (2 pre-[8] and 4 post-course essay), "Reflection as ethical" (4 post-course essays) and "Reflection as considering perspectives of others" (1 pre- and 1 post-course essay). Due to length limitations, these will not be described in this paper.

#### 2) Depth Category Findings

The Depth category is comprised of themes indicating depth of thinking or knowledge as an element of reflective engineering. For example, the most prevalent theme was "Reflection as thinking deeply" (2 pre- and 3 post-course essays). Keywords/phrases included: *thinking deeply*, *a lot of thought*, *intense thought*, *thinking things over*, *ponder critical issues*, and *put effort into decisions*. A representative quote for this theme is provided from the post-course essay of Student 10 (which was coded for multiple themes as indicated below):

> *"To some extent, reflection is a slow process that requires the individual to put more effort in his/her decision in engineering practice."* (2)

Other themes in this category were: "Reflection as providing solutions" (2 pre-course essays) and "Reflection as applying theory to practice" (1 pre-course essay).

#### 3) Metacognition Category Findings

The Metacognition category is comprised of themes that show awareness of metacognitive aspects of reflection. For example, the theme "Reflection as evaluation" (6 pre- and 8 post-course essays) is comprised of passages indicating that reflection in engineering means evaluating or considering something. Keywords/phrases included: *evaluating*, *re-evaluating*, *processing results*, *considered*, *taking into consideration*, *considering thought processes*, and *weighing pros and cons*. A representative quote from this theme is the following from the post-course essay of Student 9:

> *"Reflection in the context of Engineering practice means putting in[to] consideration and being observant of the processes taken in the course of practicing Engineering."* (3)

Other themes in this category were: "Reflection as personal activity" (4 pre- and 4 post-course[9] essays) and "Reflection as awareness of process" (1 post-course[10] essay).

#### 4) Time Category Findings

The Time category is really a sub-theme of the Metacognition category but is presented separately because of its prevalence. It is comprised of themes that show awareness of temporal aspects of reflection. For example, the most prevalent theme "Reflection as backward-looking" (6 pre- and 3 post-course essays) is comprised of passages, either explicit or implicit, indicating that reflection in engineering is backward-looking in time. Keywords/phrases included: *looking/thinking back*, *past*, *previous*, *review*, and *after*, as well as implicit references via the use of past tense where appropriate. A representative quote from this theme is the following from the pre-course essay of Student 2:

> *"Reflective engineers look at past projects and examine what could be improved or altered to hopefully produce a more perfect end result."* (4)

Other themes in this category were: "Reflection as forward-looking" (5 pre-[11] and 3 post-course essays), "Reflection as taking time" (4 pre- and 1 post-course[9] essays) and "Reflection as ongoing" (2 pre- and 1 post-course[9] essays).

### B. Survey Findings

The results of our pre- and post-course surveys are summarized in the box-plots of Fig. 1 and Fig. 2, respectively. Fig. 1 shows that the self-reported scores on the pre-surveys was relatively high, with median values above 3.5 out of 5 for all but one of the measures. However, the mean score for Contextual Competence on the pre-survey was 2.8. Fig. 2 shows similar responses for the post-course survey except that the mean Contextual Competence score rose to 3.3. This increase of 0.5 on a 5-point scale was found to be statistically significant ($p<0.005$ using a 2-tailed, paired *t*-Test, $n=10$) with an effect size of 0.97 (Cohen's *d*). The aggregate mean values and changes in mean for each construct/variable are shown in the column-chart of Fig. 3. While most of the other variables/constructs showed small changes, only that for Contextual Competence was statistically significant above the 95% confidence level.

## IV. Discussion

In this section, we discuss the findings presented above, tie the essay findings to the survey findings where possible and appropriate,[12] and suggest answers to the research questions.

#### 1) Breadth Category & Contextual Competence Construct

The essays showed a <u>large increase</u> in the number of students who identified <u>breadth of knowledge/perspective</u> as an element of reflective engineering after the course. Specifically, 4 of 10 pre-course essays contained passages coded with themes in the breadth category, while 9 of 10 post-course essays contained such passages.

This increase in consideration of breadth was confirmed by the Likert-type survey results for the Contextual Competence construct, which showed a statistically significant increase well above the 95% confidence level pre to post. This construct was designed to measure "an engineer's ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions" [15].

The fact that students both demonstrated better awareness and appreciation of the importance of these broader contexts of engineering in their post-course essays and also self-reported being better able to anticipate and understand these broader contexts in the subsequent post-course surveys suggests answers to both of our research questions: 1) the course increased student awareness and appreciation of breadth of knowledge and/or perspective and 2) the course increased student abilities to anticipate and understand the constraints

[8] This includes quote *(1)*, which was coded for both themes.

[9] This includes quote *(2)*, which was coded for four themes.

[10] This includes quote *(3)*, which was coded for both themes.

[11] This includes quote *(4)*, which was coded for both themes.

[12] Note: length restrictions also constrain discussion of the qualitative findings to a simple quantification of this relatively rich data (e.g., by making infeasible any comparison of pre to post results at the individual level for even a selection of students), and limit discussion of the mixing of methods (e.g., whereby the data is explored from multiple perspectives).

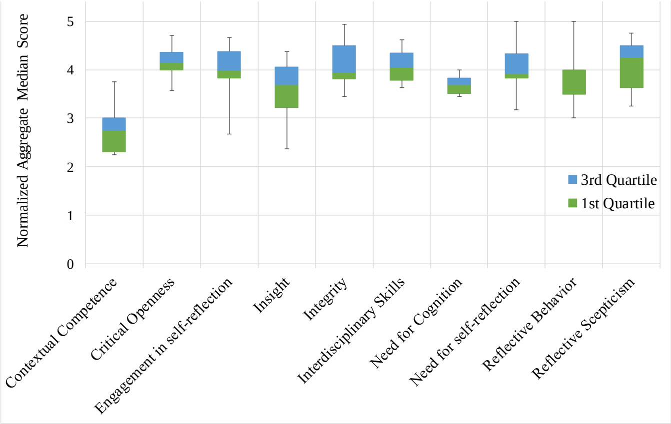


Fig. 1. Box-plot of Pre-Survey Results. *(n=10 students)*

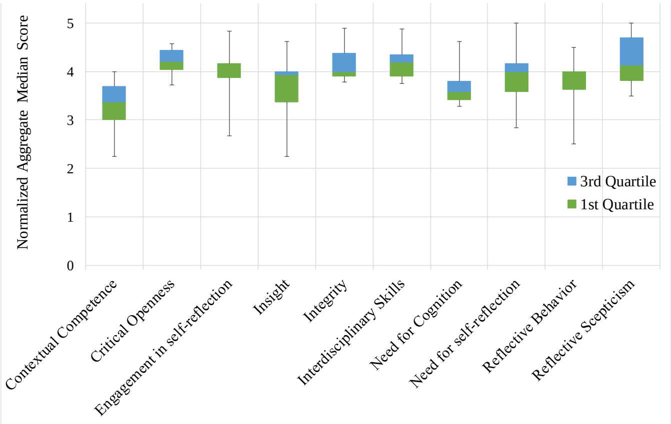


Fig. 2. Box-plot of Post-Survey Results. *(n=10 students)*

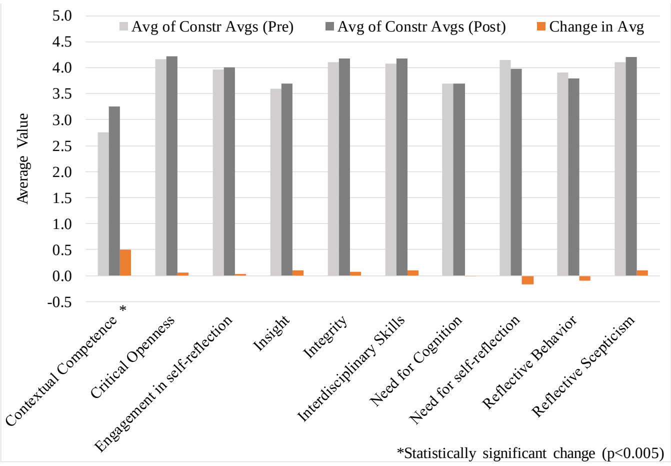


Fig. 3. Pre- & Post-Survey Aggregate Means & Deltas by Construct *(n=10)*

and impacts of the broader contexts of engineering by nearly one standard deviation.

*2) Depth Category & Need for Cognition Construct*

The essays showed a slight decrease in the number of students who associated depth of knowledge with reflection in engineering after the course. Specifically, 4 of 10 pre-course essays contained passages coded with themes in the depth category, while only 3 of 10 post-course essays contained such passages. This was the smallest category with the fewest codes and themes. The change in depth of knowledge was probably not significant at the aggregate level, though analysis at the individual level could provide meaningful insight. For example, for Student 6, the quality and sophistication of her response increased significantly by the end of the course as her conceptions of reflection moved from an exclusive focus on providing solutions to notions of evaluation and ethics.

A survey construct that maps well to the Depth category is Need for Cognition, which "refers to an individual's tendency to engage in and enjoy effortful cognitive endeavors [and] … is predictive of the manner in which people deal with tasks and social information" [11]. Since this inductively derived category and survey construct show clear similarities, the fact that we found no measurable change in Need for Cognition is consistent with the findings of the essay analysis.

*3) Metacognition Category & Reflection Constructs*

The essays showed a moderate increase in the number of students who identified metacognitive aspects as elements of reflective engineering after the course. Specifically, 6 of 10 pre-course essays contained passages coded with themes in the metacognition category, versus 9 of 10 post-course essays.

This increase in metacognitive aspects could possibly be reflected in the slight increase observed in Reflective Scepticism, which conveys "the tendency to learn from one's past experiences and be questioning of evidence" [14]. The "Reflection as Evaluation" theme seems to parallel the latter part of this. However, we also saw a slight decrease in Reflective Behavior, which "involves the ability to reflect on one's biases and the choices one makes when defining problems or interests, building understanding, problem solving" [13]. Regardless, this qualitative change from the essays was not mirrored by a corresponding statistically significant change in any of the related survey constructs.

This is likely due to the small sample size and the inherently high scores of our group of students on the pre-surveys. Since the course was an elective course, it is likely that we experienced some degree of self-selection bias in that students with an interest and proclivity for reflective behavior chose to enroll in the course and those with less interest and ability for reflection did not enroll. This could explain the skew of most scores in the pre-surveys toward the high end of the scale. Furthermore, the small values of change observed in the surveys could be appropriate for the short time-frame allocated by a one-semester course. As [9] indicated for their Reflective Judgment Model, "[t]he amount of change was smallest in studies of short duration (3–4 months); significant increases were consistently observed in studies of at least a year's duration." With this in mind, we are considering adding a longitudinal dimension to our study.

*4) Time Category & Reflection Constructs*

The essays showed a large decrease in the number of students who associated temporal aspects with reflective engineering after the course. Specifically, 8 of 10 pre-course essays contained passages coded with themes in the time category, versus 4 of 10 post-courses essays.

This decrease in time considerations could be an unintended consequence of the course, which may have focused too much on the broader contexts of engineering and not enough on the practical day-to-day strategies for (and uses of) reflection. The pre-course conceptions of forward and backward-looking dimensions of reflection in the essays fits well with the general definition of reflection on experiences provided by [3]. In future iterations of the course, we will consider providing this definition of reflection and perhaps adding some practical exercises to encourage a more balanced view of both the forest (broader contexts) and the trees (individual experiences).

Survey constructs that map well to the Time category include those mentioned for the Metacognition category above, as well as Engagement and Need for Self-Reflection [11]. Unfortunately, space constraints limit further discussion.

## V. Conclusions

In this paper, we presented select findings from a mixed-methods study on an experimental seminar in civil/ environmental engineering. Throughout the course, we explored ways of developing skills for reflective thinking and ethical decision-making using the arts and humanities. Activities included Visual Thinking Strategies (VTS) [1], in-class readings & discussions about dilemmas, essay writing, and portfolio assignments. The skills these activities aim to develop are key for Peace Engineers seeking to use their knowledge to address complex issues like sustainability and social equity.[13]

While the class was small, comprised of a dozen graduate students, results were encouraging. For example, findings from qualitative thematic analysis of pre- and post-course essays showed an increase in student recognition of the importance of breadth of knowledge/perspective. This finding was supported by pre-post Likert-type survey results, which showed a statistically significant increase ($p<0.005$) in Contextual Competence [15] with a relatively large effect size (Cohen's $d$ = 0.97). These findings, while preliminary, suggest the following answers to our research questions: 1) the course increased student awareness and appreciation of breadth of knowledge/ perspective, and 2) the course increased student abilities to anticipate and understand the constraints/impacts of engineering's broader contexts by nearly one standard deviation.

Not only did this pilot course appear effective by several measures, it was also very well received by the students, with end of semester student evaluations showing scores of 4.9 (out of 5) for Meeting Course Objectives, 4.8 for Instructor Effectiveness, and 4.6 for Valuable Learning Experience ($n$=8). We look forward to using our findings to improve the course and offer it again.

While opportunities may abound for engineers wishing to use their knowledge for peace-building, doing so effectively requires additional skills and abilities beyond those found in traditional engineering programs. Courses and curricula like what we propose can help engineering students and the profession to engage in reflective ways of thinking that will increase attention to peace, and the elements necessary for promoting and sustaining it, while also guiding well-intentioned actions and reducing unintended consequences.

[13] For example, VTS directly promotes communication and cultural understanding, which are essential components of any peace-building endeavor.


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