Integration of Critical Reflection Methodologies into Engineering Service-Learning Projects

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Integration of Critical Reflection Methodologies into Engineering Service-Learning Projects: A Case-Study

Abstract

This paper focuses on a case study utilizing critical reflection methodologies in an engineering, service-learning course at a small, liberal arts college. The college started the engineering department in 2009. As a new program, the department has been working to accredit programs in four disciplines: chemical, civil, electrical, and mechanical engineering. The department is designing the degree programs to take advantage of the Catholic, liberal arts mission of the college. The development of courses that highlight these aspects in the curriculum is a priority of the department. Service-learning courses are able to incorporate the Catholic, liberal arts with an engineering project. Critical reflections in such courses help students to analyze the experiences working on the project and provide the framework for them to integrate these experiences into their careers.

The authors discuss a course they developed that introduces students to the methodologies of engineering for human development. Students perform background research to conduct a community appraisal, work with the community to identify needs, develop a project proposal, and design a solution that will be implemented in the community. Students then work with the community, both remotely and in-person, to implement the chosen solution. This type of work fits well with the Catholic mission of the college and provides a good opportunity to introduce critical reflection techniques.

In this paper, the authors present two different methods of critical analysis: classroom discussions and critical reflection papers. The paper provides an overview of how the techniques were introduced, what topics were discussed, and the outcomes of the reflections. Additionally, the authors discuss the assessment of these reflections for integration into our ABET assessment plan. Finally, the paper provides recommendations for integration of critical reflections into other classes.

I. NEW CHALLENGES, NEW INITIATIVES

The engineering profession has acknowledged the need for engineers of the 21st century to have a broader skillset than in the past. For example, ASCE's Civil Engineering Body of Knowledge outlines a vision for the profession that expands into areas such as sustainability, public policy, teamwork, and globalization [1]. ABET has also addressed this need by incorporating similar concepts in student outcomes such as "knowledge of contemporary issues" and ability to "understand the impact of engineering solutions in a global, economic, environmental, and societal context." [2].

Diverse Responses

Engineering educators have responded to these new demands with co-curricular and curricular

initiatives. For example, many students have gained exposure to global issues in engineering through participation in student chapters of Engineers without Borders, founded in 2002 [3], or through school-sponsored international engineering trips, such as those previously offered at that authors' institution. While these may provide an invaluable learning experience, they are typically co-curricular, which prevent their formal contribution to the outcomes of engineering programs.

Other institutions have designed academic programs or courses to intentionally expand the formation of their engineering students. One example is the Mortenson Center in Engineering for Developing Communities (MCEDC) at the University of Colorado Boulder, which aims to educate students in the technical and non-technical aspects of community development. Since 2003, when the foundations for the Center were laid, it has grown into a program where undergraduates can receive a minor or certificate in Global Engineering and where advanced degrees and certificates are offered in the study of Engineering for Developing Communities [4].

Another means to address the new demands in engineering education is service-learning, which can be defined as "an academically rigorous form of experiential education in which students engage in activities that address human and community needs, together with structured opportunities for reflection designed to achieve desired learning outcomes" [Jacoby (1996c), as cited in [5]]. One framework for service-learning in engineering is Engineering Projects in Community Service [6], which was founded at Purdue University in 1995 and has since expanded to more than 30 institutions of higher education throughout the country and across the globe. This credit-bearing program utilizes a multidisciplinary approach that engages students in long-term design projects to address needs in the local community [7].

Reflection in Engineering Education

In addition to redesigning curricular and co-curricular opportunities, engineering educators have shown a growing interest in the use of reflection as a methodology to prepare engineering students for the demands of the modern world. This is manifested by the work of Sepp et al. [8], which shows that the number of papers per year referencing reflection in ASEE conference proceedings has increased from 6 in 1996 to over 200 in 2014. Furthermore, they found that between 2008 and 2014, written reflection was the most commonly described means of "operationalizing" the reflection discussed in the ASEE papers. These written reflections included essays, surveys, journals, portfolios, and short answer questions. Group or in-class discussions and other activities were also mentioned.

While a comprehensive literature review on reflection in engineering education is beyond the scope of this paper, the authors conducted an abbreviated review in order to give context to the use of critical reflection in the present case study. Of particular interest to the authors were the following questions: a) Are critical reflections in engineering education effective in *achieving* learning outcomes? and b) Are critical reflections in engineering education effective in *assessing* learning outcomes? During this investigation, two additional topics of relevance emerged: c) Factors that contribute to successful implementation of reflection and d) The recognition of the need for further research on reflection.

a) Critical Reflections and Achieving Learning Outcomes

The literature reviewed indicated that educators sought diverse learning outcomes through use of reflection, with many focusing on the development of skills beyond strict technical abilities, such as teamwork [9][10]. It is interesting to note, however, that reflection upon these "soft" skills or more consistent reflection over the duration of the project was, in some cases, associated with results linked to "hard" skills, such as higher performance as a team [9][Valkenburg & Dorst (1998), as cited in [11]].

In their investigation of the use of reflection in health professions education, Mann et al. recount a study by Sobral [(2001), as cited in [12]] which indicates a positive relationship between "deep learning" and reflection, while Hake's work [(1998), as cited in [13]] points to test scores that indicate students' "conceptual understanding" was higher in classes that implemented "interactive-engagement methods."

*b) Critical Reflections and Assessing Learning Outcome**s***

An interesting debate was discovered around the theme of assessment and reflection: authors in the field disagree as to whether reflection activities and assignments should be assessed at all. Some recommend that professors not collect reflections in order to emphasize the personal nature of reflections [Seattle Central College FG06 and Arizona State University FG10, both as cited in [14]]. Otherwise, students may be distracted from their own thoughts and experiences by teachers' expectations [14]. Others indicate that students were only saying what instructors wanted to hear, a risk which would naturally intensify in proportion to the weight given to the reflections in grading [15]. Relatedly, Mann et al. cite certain authors' consideration of whether assessing reflections may be "counterproductive" in some cases if doing so were to threaten students' experience of "safety" [Pee et al. (2002), as cited in [12]]

Multiple other authors, however, described methodology and motivation for assessing students, sometimes even including rubrics used [9][16][O'Brien (2013), as cited in [5]][Bradley (1995), as cited in [5]]. It was suggested that assessing reflections could motivate students to take the assignment seriously [Georgia Tech FG08, as cited in [14]] and that not doing so may have the opposite effect [12], a concern shared by the authors of the present paper. Jolly and Radcliffe [10] even observe that increasing the percentage of the grade assigned to reflection tasks had a "significant effect" on how seriously students approached the task.

Some authors encouraged assessment for the purpose of helping students learn *how* to reflect (for example, see [12]). This is of particular importance, since reflection is oftentimes new territory for engineering students [Arizona State University FG08, Bellevue College FG07, Bellevue College FG10, Clarkson University FG01, all as cited in [14]]. Furthermore, there are indications that a key factor in developing reflexive skills is the attitude towards and modeling of these skills by mentors and faculty themselves [10][12]. Providing formative assessment on critical reflection tasks seems to present an opportunity to model reflection for students [Georgia Tech FG11, as cited in [14]].

On a larger scale, Davis et al. [9], describe how multiple universities have used assessments of reflection tasks to document ABET outcomes.

It seems that the decision whether to assess or not assess a reflection depends on the instructor's

motivation for introducing reflection in the first place. While assessment seems appropriate for reflections geared towards understanding of course content, integration of bodies of objective knowledge, and application of foreign bodies of objective knowledge to the field of engineering, it could be argued, as sources indicate above, that with other purposes – such as personal development or self-assessment – students would be more truthful if they did not anticipate being assessed or even needing to turn in their reflections. However, one must keep in mind the point already cited: assessment, even of subjective reflections, may help students improve their reflection skills.

c) Factors in Successful Reflection

A number of the sources reviewed make recommendations for how to support reflection. These can largely be distributed into three categories: a) educating students about reflection; b) intentionally and explicitly connecting reflection to learning outcomes; and c) offering practical and cultural supports for reflection.

i. Educating students about reflection

"Reflection" has multiple meanings and associations in the English language. Even within the field of service-learning and engineering education, one will quickly find diverse definitions (See Table A1 in Appendix). Perhaps because of this plethora of uses of "reflection," several authors highlight the importance of clarifying for students what instructors mean by "reflection" so as to avoid confusion [15][Bellevue College FG07, as cited in [14]]. This is recommended in the service-learning literature as well [5].

ii. Intentionally and explicitly connecting reflection to learning outcomes

An observed or suspected obstacle to reflection is the thought that it is irrelevant to the task at hand [Cal Poly-SLO FG02, as cited in [14]][12][15][10]. This challenge seems to be addressed by the recommendation found in the literature to establish a clear link between reflection and the learning or course outcomes. This is in reference both to planning of reflection activities [Rose-Hulman Institute of Technology FG09, as cited in [14]][9][17] and also in making this connection explicit to students [14][9].

iii. Practical and cultural supports

Implementing critical reflection poses unique challenges to engineers and engineering students [Beder (1998), as cited in [10]][16][18], which may explain why multiple authors offered input on how reflection could be presented in a more favorable light for this population. For example, sources mention using alternate terms instead of "reflection" [Arizona State University FG10, as cited in [14]] and basing reflection activities off of formats used in professional settings, such as a log [10]. This will depend, once again, on the learning objectives for the course. For instance, some instructors may want their students to emphasize written communication and narrative skills; in this case, certain kinds of logs may be less effective in achieving the desired objectives.

Faculty and mentor example of and attitude towards reflection, as well as the general building of a culture that supports reflection, were also noted as factors to success [12][10].

Lastly, since lack of time was indicated as an obstacle to the development of students' habits of reflection, a seemingly obvious yet important element in supporting reflection is simply giving students the opportunity to do so [19][16].

d) Call for more research

Though scholarly attention to reflection in engineering education has increased [8], the topics for investigation are by no means exhausted. On the contrary, scholars continue to identify points for further study. Some of these suggestions encourage assessment of the impact of reflection, such as the proposal by Turns et al. [20] to investigate the meaning students assign to experiences as a result of intentional reflection compared to the meaning they assign without intentional reflection. The larger number of the suggestions by Turns et al. [20], however, tend towards research on the way students reflect, which could then be used to help increase reflection; this seems to already assume the value and benefit of reflection. Similarly, most of the potential study topics posed by Thomas et al. [14] are related to the tips they compiled for how to successfully implement reflection, which seems to indicate their prior acceptance of the strategy's merits. While the fruits of the suggested research will likely enrich the work of engineering educators, it seems that many in the field are yet to be convinced of the value of reflection methodologies in the first place. To that end, more research on the academic impact of reflection – such as the suggestion by Turns et al. [20] mentioned above – will also be essential to the widespread acceptance of this methodology. This need can also be inferred from the astute observation made by Mann et al. [12] that "the evidence to support and inform these curricular interventions and innovations remains largely theoretical and it is unclear which approaches may have efficacy or impact (Andrews 2005)."

The present paper seeks to offer an initial framework for obtaining data on the impact of critical reflection strategies. It describes the history, design, implementation, and evaluation of an undergraduate engineering service-learning course, with particular emphasis on the critical reflection component. The authors believe that these and similar efforts on a larger, more generalizable scale, will help establish the credibility of critical reflection in the engineering field. The subject course was taught at a Catholic, liberal arts college with a full-time undergraduate enrollment of approximately 2000 students. The engineering department, established in 2009, has approximately 180 students.

II. COURSE OVERVIEW

Background and context

Motivation

In 2014, Engineering students at the authors' institution proposed and began planning a mission trip that would enable them to put their technical skills and training at the service of a community in a developing country. Students identified and designed projects that could be implemented during a week-long spring break trip. In 2015, students made their first engineering mission trip to Guatemala, where they constructed a roof system for a sewing center. The next year, in 2016, students built a water storage facility in Ghana.

Student and faculty enthusiasm for these trips was high and the outcomes were positive. However, for both faculty and students, the demands of this co-curricular project often gave way to the demands of other responsibilities such as those of academic courses. This presented a

challenge to timely completion of the project, and also limited the educational benefit of the design experience to the two to three individuals who were available to move the project forward. Therefore, in order to encourage steady project progression and to involve more individuals in the design work, the instructors decided to build an engineering elective course as an academic base for the mission trip.

Student Outcomes and Course Objectives

The ABET A-K framework provided the structure for the student outcomes of the course. One main outcome this course was designed to address was Outcome H, "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [2]. In a survey of recent graduates conducted by the authors' institution for the Mechanical Engineering Program's ABET Self-Study report, alumni respondents ranked Outcome H lowest among all ABET outcomes when considering how the curriculum delivered each of the ABET outcomes. This course was intended to help the department strengthen delivery of Outcome H.

One objective for the course was for students to gain a better understanding of the role of engineers in development work. This was done through the design of a project to support a developing community. The project was then implemented by students who chose to travel to the community on an optional spring break mission trip.

Another objective of the class was to illustrate how students can incorporate elements of Catholic Social Teaching (CST) into their work as engineers. Broadly speaking, CST is the body of work within the Catholic Church that focuses on social justice, including issues related to poverty and wealth, economics, social organization, and the role of government. Human dignity and development are also major aspects of this teaching (for more details, see [21]). Many elements of CST are included in the required theology classes of the college, and the instructors wanted to provide engineering students with a practical opportunity to apply that content in the context of their disciplines.

Final course structure

To facilitate planning, the course was held over two semesters. The fall semester course was two credits and met twice a week. In the spring semester, the course was one credit and met twice a week during the first quarter in order to ensure the project was completed prior to spring break. The combined fall and spring semester courses counted as a three credit engineering elective for all disciplines. The course was open to all engineering majors having junior standing. Students were encouraged, but not required, to go on the mission trip.

Nine students enrolled in the original course, which was offered as a special topics course. However, in the future the instructors plan to make the course available as a catalog course. The engineering faculty and administration have been supportive of this course since it supports the mission of the department and the college.

Partnerships

In order to identify a project suitable for the course, the instructors coordinated with the MCEDC. Through this collaboration, the instructors began a partnership with a Catholic parish in the Andean village of Orurillo, Peru. The Catholic prelature responsible for the parish helped identify and eventually implement a suitable project. They provided essential information on all aspects of the project. It was also through the MCEDC that the instructors learned of Creatio, a non-profit organization which facilitates international mission trips [22]. This organization, which already had a relationship with Orurillo, created a mission trip to accommodate the engineering students and faculty, thus providing critical support regarding in-country knowledge and contacts, project advice, and travel logistics.

On campus, the instructors took advantage of the Catholic, liberal arts mission of the institution and consulted a colleague in the Theology department for guidance on incorporating formation in CST into the course. The fruit of this collaboration was a list of required readings for the students (see Table A2 in Appendix). The instructors were also referred to the institution's Coordinator of Service-Learning, who identified use of critical reflection as a key component in service-learning methodology and as a means to consider the technical aspects of the course in light of the assigned CST texts. The college's Ministry department assisted with many planning details of the optional mission trip and with fundraising of the costs for the trip and project supplies. Another key collaboration occurred when one of the college's sponsoring institutions allowed students to build a prototype of the project on their property.

Project

Student involvement in this process began the summer before the course began, when two students traveled to Peru in person to identify local needs. Ultimately, through contacts developed as a result of the trip, the group partnered with the local prelature which operated a food program for school children. Greenhouses had provided supplementary vegetables for the program in the past, but had fallen into disrepair. As such, a new greenhouse was identified as a need for the community.

The class developed two projects based on this need. The first project was to design a new greenhouse structure. For this project, the students determined the overall size of the structure, identified the appropriate orientation, identified local materials, conducted the structural design, and developed construction plans. However, in class discussions, students determined that the growing environment (temperature, humidity, sunlight, etc.) the greenhouse would provide was unknown. As such, a second group of students in the course developed an environmental monitoring system. This group researched sensors and data logging systems and developed a design to collect environmental data that could be used to inform future design decisions. Students, faculty, and community partners maintained contact during the academic year as the project progressed.

In order to manage the risk associated with implementing the designs at a remote location, the students built prototypes of their designs. The greenhouse group constructed a full-scale mock-

up of the greenhouse. This effort provided the students with the ability to work through construction issues prior to going to Peru. Additionally, the data monitoring group built a prototype of the environmental monitoring system. This prototype allowed the students to ensure that all the components worked together as expected and allowed students to test programs for the datalogger.

Text

The text adopted for the course was Amadei's *Engineering for Sustainable Human Development* (subsequently referred to as EfSHD) [23]. The text describes the ADIME-E framework which the instructors adopted for the class. The framework includes the following phases: appraisal, design, implementation, monitoring and evaluation, and exit strategy. The CST readings were also assembled into a course packet and provided to the students as another course text.

Deliverables

The instructors included deliverables to address both aspects of the course: the design component and the reflective component. Thus, for the design component, students provided preliminary design reports, final design reports, oral design presentations to stakeholders, and construction plans. For the reflective component, students participated in class discussions and wrote critical reflections. These latter two items are discussed in more detail in the following section.

Critical reflections

The subject course used a definition of critical reflection offered in Jacoby [5] - "the process of analyzing, reconsidering, and questioning one's experiences within a broad context of issues and content knowledge" - and implemented two different critical reflection methodologies: written reflections and class discussions. These two different methodologies were selected to provide complementary opportunities for reflection of the course. The following section discusses how the authors integrated these two methods into the course.

Written Reflections

For the written reflection assignments, the instructors provided handouts describing the assignment. The first part of the handouts explained the reason for the critical reflection and included the definition of critical reflection cited above. The instructions also tied the reflection to ABET Outcome H ("the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context") [2]. The handouts then included a set of three reflection prompt questions. See Table 1 for a listing of the reflection prompt questions.

Table 1. Critical reflection prompt questions

Critical Reflection	Prompt Questions	Course Objective
1	● What roles do engineers have in human development? (CR1P1) ● How can you, as an engineer, impact human development in developing countries? (CR1P2) ● How has working on this project changed the way you think about the role of an engineer in society? (CR1P3)	Role of engineers in development
2	● How will our project support the development of the people? (CR2P1) ● What impacts (positive and/or negative) might this project have on their development (spiritual, economic, environmental, and societal)? (CR2P2) ● How does the project address the larger problems the community is facing? (CR2P3)	Role of engineers in development
3	● How has this project changed your views on the role of documentation, communication, and teamwork in engineering project development? (CR3P1) ● How does Catholic Social Teaching (CST) treat human development? (CR3P2) ● What are the differences and similarities between human development as outlined by CST and that described by Amadei? (CR3P3)	Integration of CST with engineering work

The authors chose the questions based on a recommendation from the service-learning literature to tie the questions to the course objectives [5]. As such, the questions were chosen to see how students viewed the role of engineers in human development and to evaluate the students' perceptions of how CST can inform their work as engineers. The first objective was the main focus of the first two critical reflections. The first reflection focused on the role of the individual engineer while the second focused on the impact the project had on the community. The last written reflection addressed the second objective. In addition to the course objectives, the authors wanted to assess student outcomes, in particular ABET H. The first two reflections addressed this outcome.

Students were asked to write a reflection that answered each of the three prompt questions. A minimum of one paragraph was required for each question. Students were required to include references to the readings and, in order to ensure the two forms of reflection were complementary, the instructors indicated that students should include information from the class discussions in their written reflections as well.

Jacoby proposed a rubric by K.M. O'Brien [O'Brien (2013), as cited in [5]] for assessment of critical reflections in service-learning classes. The instructors adapted this rubric for use in the class. This adapted rubric is shown in Table 2 below. It was included in the handout so that students understood how they would be assessed. The instructors applied the rubric to each reflection prompt question. Three points were also assessed for the mechanics of the paper. Thus, each reflection was worth a total of 15 points.

Table 2. Critical reflection rubric (adapted from O'Brien (2013), as cited in [5])

Assessment	Points
Exceptional, thoughtful critique that truly integrates course concepts and research into an analysis of the experience	4
Very good, thoughtful critique that applies course concepts and research	3
Average to below average analysis; does not integrate course concepts and research in a thorough manner	2
Below average analysis; no integration of course concepts or research	1
Did not complete the assignment	0

Class discussions

The course included a total of 14 class discussions over the two semesters. Students read sections from the EfSHD text or from a relevant CST source document. In general, the instructors tried to allow the students to lead the discussion as much as possible, occasionally commenting, prompting with questions or engaging the conversation. Example discussion questions are paraphrased in Table 3. Students in general, and engineering students in particular, are often reluctant to join in class discussions. To encourage participation, the instructors asked reluctant students for their opinions. Students received a grade for participation in the discussions. However, in order to encourage an open discussion, the instructors did not provide criticism of the class discussions. These discussions provided the opportunity for students to discuss the readings with their peers and hear alternative viewpoints regarding the topic. The discussions were not time-limited typically: some would last ten minutes and on at least one occasion the discussion lasted the entire fifty-minute period.

Table 3. Sample discussion questions

Amadei defines the attributes of a global engineer. What additional skills are needed to do this type of engineering work?
The text lists several criteria that contribute to the long-term benefits of a project. How does our project fair?
The author stresses the need for community involvement in development projects. What can we do to ensure the community is involved in our project?
Did you see any examples in your previous trips that tie into Pope Francis' comments about how consumerism affects people's ability to work together as a community?
Paul VI says "*created goods should flow fairly to all*." What are our responsibilities in this regard?
How does Benedict XVI's assertion that "Only in charity, illumined by the light of reason and faith, is it possible to pursue development goals that possess a more humane and humanizing value," compare with how some development work is conducted?

Note: Questions were paraphrased from the author's class notes.

III. RESULTS

The effectiveness of the critical reflection methods used in the course were of interest to the authors. Additionally, the authors wanted to determine how well the course achieved the course objectives and student outcome ABET H. This section discusses the rating of the students' critical reflection papers and the students' perceptions of the critical reflection methods employed. Additionally, the authors provide a summary of the students' perceptions of how well the course achieved the intended objectives and outcome.

Critical reflection papers

Both instructors graded the critical reflection papers using the rubric shown above. When there was a score difference between the instructors, one of two resolution procedures followed. In some cases, after discussing the rationale, one of the instructors adjusted his score to match the other. In other cases, the instructors averaged the two scores. In all cases, the instructors' rubric scores were within one level of each other. Results of the final rubric scores on each prompt are presented in Figure 1 as box plots. (Results for CR3P1-P3 are not included since the data was not available at time of publication.) The results indicate that, in general, the students' scores were between 3 and 4. This indicates that they had a good grasp on the course concepts.

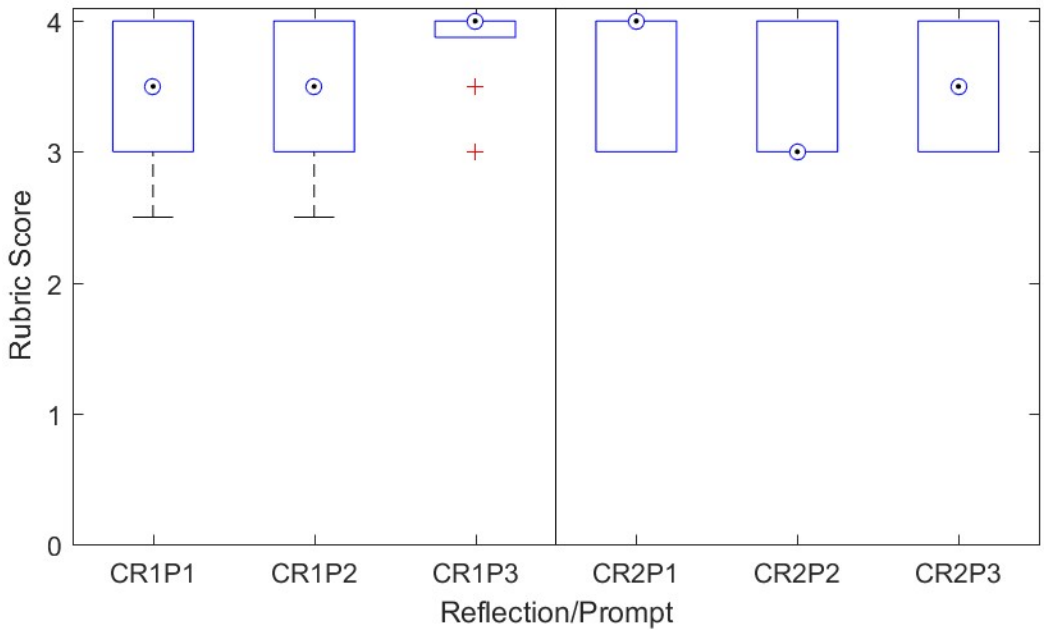

Figure 1: Box plots for rubric scores on each prompt. The "target" symbol indicates the median final score for that element among all nine students. The boxes span the 25th to 75th percentiles.

The instructors gave students feedback on their critical reflection papers not only using the rubric scores, but also in the form of comments directing the students on additional reflection. An example of this type of feedback from the question "What roles do engineers have in human development?" (CR1P1) follows:

> *"This reflection focuses on the role of engineers insofar as they have a wide impact through their designs and their responsibility to have standards to ensure benefits to others. This is supported by a quote describing responsibility to cultivate the common good. I think the reflection would benefit from perhaps formalizing the definition of human development so that additional dimensions could be brought in (education, culture, spirituality, etc.) as were discussed in the reading, instead of the limited focus on standards. Score: 2"*

Class discussions

Before the course began, there was some concern about how these discussions would go since this is not a typical classroom mode for engineering courses (from both the student and instructor perspective), but both instructors were happy with the results. This could have been aided by being housed in a liberal arts college where students are perhaps more comfortable with this format in their general education courses.

Student feedback of the discussions on the end-of-semester *IDEA* survey [24] was generally positive as can be seen in Figures 3 and 4, below, but also in the written comments section of the survey. A few samples:

"...I think the reading/discussion to project time was about right…"

"I really liked the [CST] readings...the discussions of those were very good."

"I wish we could have had more thorough discussions…"

"I think having a little more structure to the discussions might improve them"

"I enjoyed the readings more than the discussions"

Incorporation of course readings into the engineering design process

As this was an upper-level engineering course, the major outcome of the class was the engineering design. As such, the instructors did not want the course readings (whether CST or EfSHD) to simply be "add-ons" that were separate from the design work; rather, they felt it was important that the perspective gained from these texts be useful and inform the design of the project. As part of the end-of-semester *IDEA* survey [24], supplemental questions were added by the authors which asked students how they felt that their design incorporated the ideas and perspective gained from the readings. Eight of the nine students enrolled in the course took the survey. As shown in Figure 2, most students agreed that the readings improved their design.

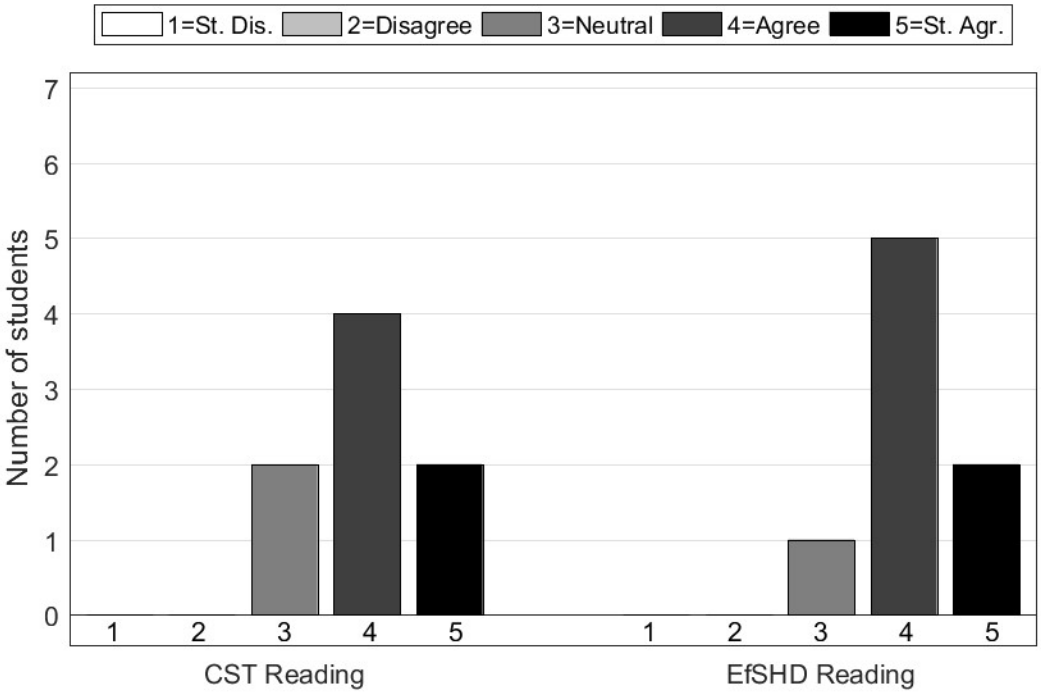

Figure 2: Student responses to end-of-semester *IDEA* [24] survey supplemental questions: "Consider how the perspective gained from each of the following elements had a positive impact on the design: (48) CST Reading (49) EfSHD Reading.

Understanding the role of engineers in human development

As described previously, one motivation for this course was to show students how the liberal arts nature of their education can come to bear on the engineering work that they do. Since the overarching theme of the readings was human development, the students were asked to rate how each element of the course shaped their understanding of human development. Figure 3 summarizes the results. As indicated in the figure, the highest rated elements were the CST readings and the discussions.

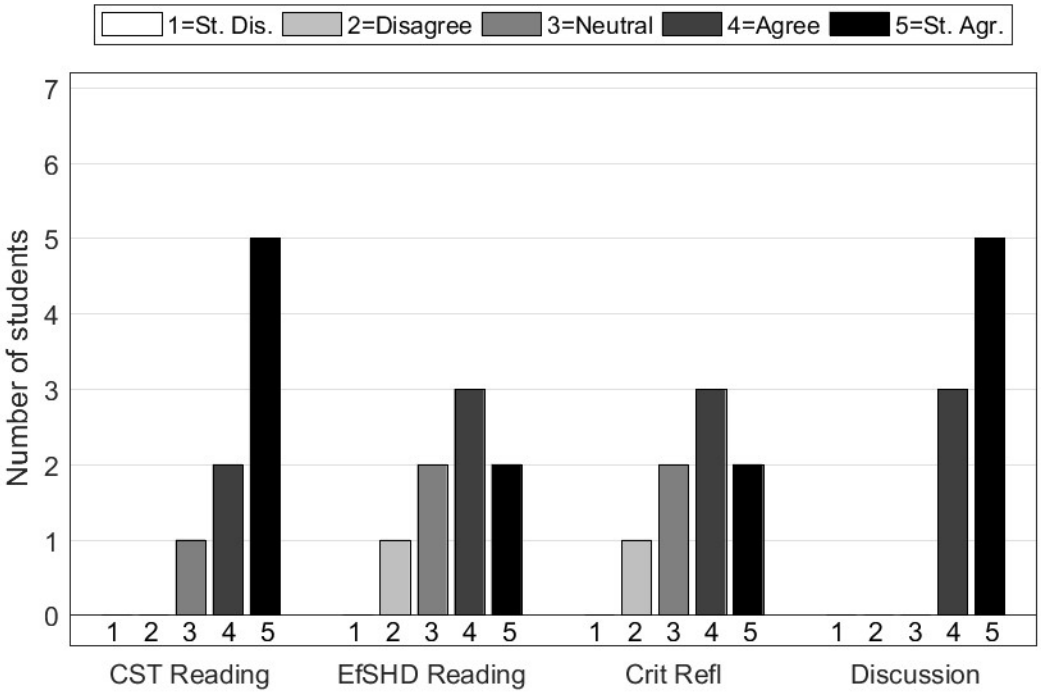

Figure 3: Student responses to end-of-semester *IDEA* [24] survey supplemental questions 52-55 "Consider how each of the following elements of the course helped you to consider and understand the role of engineers in human development. (52) CST readings, (53) EfSHD readings (54) critical reflection papers (55) in class discussions.

Indirect assessment of ABET Outcome H

In addition to the direct assessment of ABET Outcome H ("the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [2]) provided by the critical reflection papers, the course also provided a good opportunity for indirect assessment via the end-of-semester *IDEA* [24] survey. As can be seen in Figure 4, it appears all elements of the course were successful overall in helping the students attain ABET Outcome H. Future revisions of the survey could investigate each element of Outcome H (global, economic, environmental, and societal context) in more detail.

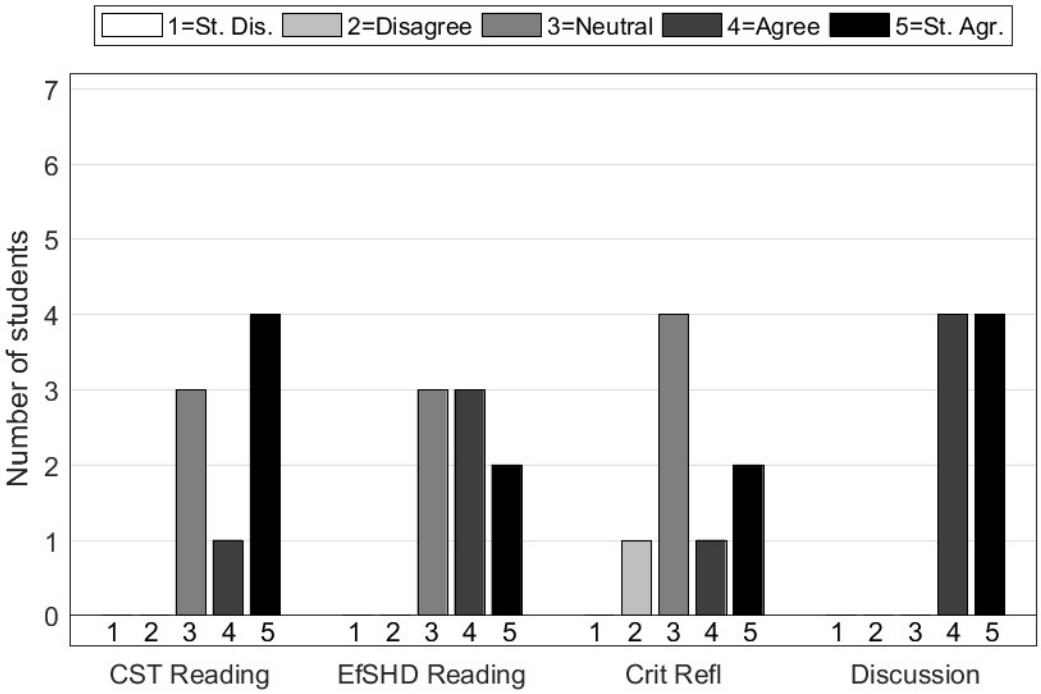

Figure 4: Student responses to end-of-semester *IDEA* [24] survey supplemental questions 56-59:"Consider how each of the following elements of the course helped you to consider and understand the impact of this engineering project in a global, economic, environmental and societal context: (56) The CST readings (57) The EfSHD readings (58) The critical reflection papers (59) The in class discussions"

Comparison of Reflection Methodologies (Papers vs Discussions)

Based on the results presented in Figure 4, students reported that the discussion mode of reflection was more beneficial in terms of understanding the impact of this engineering project in a global, economic, environmental and societal context. It is important to note again that this data represents a small sample size and the results cannot be considered statistically significant, but the trend could be of interest to other faculty considering adopting these approaches in their own courses. The authors speculate that part of the reason for the perception that discussions were more helpful was that they were more open in terms of scope than the focused reflection papers. The discussions also allowed for students to synthesize and evaluate additional points of view and perspectives brought in by the other participants. Furthermore, since the discussions were only graded based on participation and not on a rubric, the discussion environment was more collaborative in feel rather than seeming like another assessment. With that said, however, the authors feel that the papers still represent an important and valuable dimension of the course insofar as they require the student to individually sort through the concepts in the readings (and discussion) and explicitly articulate their own understanding of the course material in a deeper manner than can occur in a discussion setting.

Miscellaneous results

Based on the end-of-semester *IDEA* [24] survey results, students saw the value of this course in the context of their education and career. Students needed to use skills learned in previous courses (communication skills, CAD modeling, teamwork, structural analysis, manufacturing etc.). One valuable aspect of this project in terms of the engineering education the students receive is that the majority of people who will be responsible for fabrication of the design on site are not members of the class. Thus, the level of documentation and planning required is significant, even when compared to a capstone design course, since the design team will not be present for the construction phase. Figure 5 shows that all students agreed that the class helped their engineering and workplace skills. The overwhelming majority also said they would recommend this class to their peers.

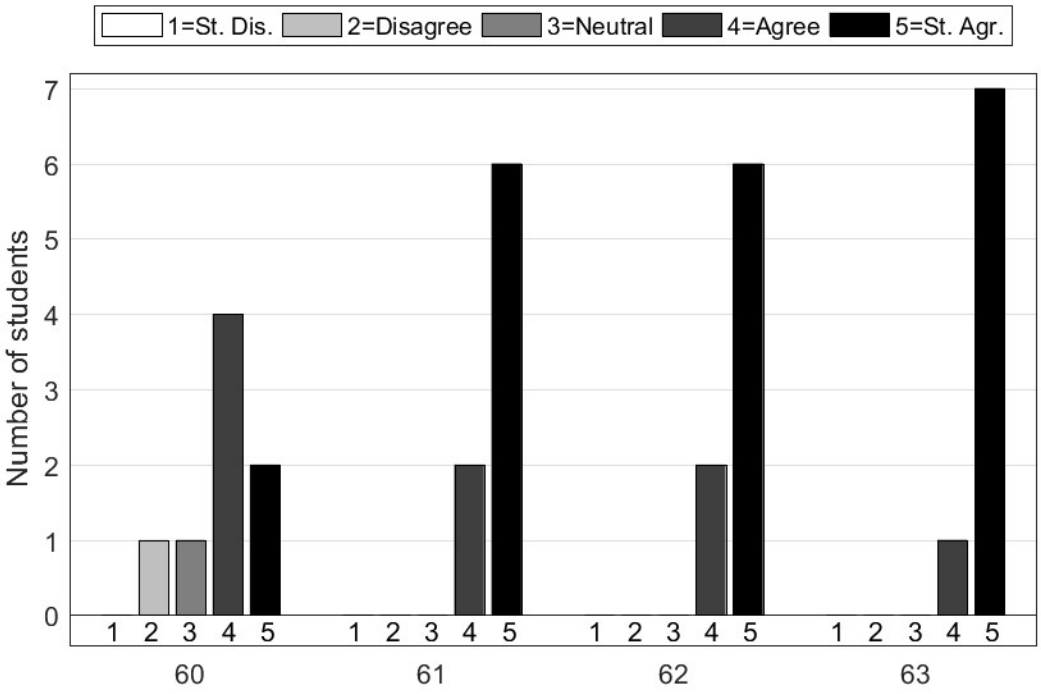

Figure 5: Student responses to end-of-semester *IDEA* [24] survey supplemental questions: "(60) The critical reflection papers helped me to consider and understand the principles of CST. (61) The service-learning experience in this course (the design project for the Orurillo community) helped me better understand engineering topics relevant to this project (62) This type of service-learning (the design project for the Orurillo community) helped me learn skills I can use in the workplace. (63) I would recommend this course to other engineering students" (Questions 60-62 adapted from [5])

One area that could be investigated in more depth in future versions of the course is how it could be used in the assessment of ABET Outcome D ("ability to function on multidisciplinary teams"). This course had nine students - five majoring in Mechanical Engineering, one double

majoring in Mechanical and Electrical Engineering and two majoring in Civil Engineering. A biology student volunteer also participated in a few classes and conducted some research in conjunction with students in the course on the growing-related issues in the region. As discussed previously, the students in the course collaborated with various non-technical groups (college ministry, Creatio, the partners in Peru and Orurillo community members). A few student comments on the end-of-semester *IDEA* [24] survey highlighted this multi-disciplinary nature of the course:

> "The experience of collaborating with the Creatio team and individuals around the world was a good learning experience and definitely applicable in my future career."
>
> "It was also nice to work with engineers from other disciplines besides my own."

IV. SUMMARY OF RESULTS

This paper summarized the implementation of critical reflections into a service-learning, engineering design course. The instructors had two main objectives for the course: to create a design experience that would allow students to design an engineering solution for a developing community and to create a course in which students could incorporate elements of CST into their work as engineers. The following is a list of conclusions from the course.

- The critical reflections were effective in identifying whether or not students had a grasp on the course concepts.
- Most students agreed that the course readings (both EfSHD and CST) improved their design.
- All evaluated course elements (CST readings, EfSHD readings, written critical reflections, and class discussions) were successful overall in helping the students attain ABET Outcome H.
- All students agreed that the class helped their engineering and workplace skills.
- Overall, the students had a positive view of the class discussions.

V. RECOMMENDATIONS FOR LARGER CLASS SIZES (SCALING-UP)

The authors are cognizant that a small class size makes it easier for the integration of these critical reflection methodologies. Class discussions, in particular, would be difficult in a large-class environment. But there are some ways in which these methodologies may be integrated. This section includes some suggestions that might be considered for use in such settings for those wishing to implement reflections.

Class discussions with a large number of students do present obstacles to implementation. Attempts to conduct a discussion in a large class would likely not achieve the desired results. As such, if one were to implement class discussions into a larger class, the authors recommend that

breakout sessions be used. The instructors found that the number of students in the course for this study (nine) was a good group size. The number of students made the discussions productive and the instructors were able to ensure everyone participated. Thus, groups should be kept in the range of 10-12 students. The instructor could visit each group to make sure the discussions stay on track. Alternatively, teaching assistants could assist with these discussions, similar to how others have used students to assist with reflection activities [10]. However, in that case, instructors should ensure that teaching assistants are properly trained in the value, purpose, and method of reflection, since it may be unfamiliar to or undervalued by them, as indicated by Jolly and Radcliffe [10], for example, who describe the challenges they encountered in having tutors assist students with reflection activities.

One reservation the instructors had about implementing written reflections was grading. However, the use of a rubric (such as the one included in this paper) made the grading of the written reflections manageable. Use of a rubric also allowed multiple individuals to grade the reflection fairly. As previously mentioned, the scores that the instructors gave a reflection were either the same or differed by only one point. This may indicate that in a larger class setting, the task of grading the written reflections could be divided among multiple people with the implementation of a rubric.

Also, the scope of the reflection (number of questions) can be scaled in order to meet the needs of the course and the capabilities of the instructor. The instructors originally had more questions on the first reflection but reduced the number of questions in order to keep the assignment manageable for both the students and the instructors. As noted previously, the written reflection should be tied to the outcomes of the course. An instructor implementing written reflections could adjust the number of questions as long as they are able to adequately assess those outcomes.

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APPENDIX

Table A1. Sample of definitions associated with reflection found in the literature

Author	Definition associated with reflection
Consortium to Promote Reflection in Engineering Education [25]	"Exploring the meaning of experiences and the consequences of the meanings for future action"
Turns et al. [20]; same source also cited in Sepp et al. [8]	"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)."
Boud et al. (1985), as quoted in [26]	"Reflection is an important human activity in which people recapture their experience, think about it, mull it over and evaluate it."
Hong and Choi [11]	"All of deliberate efforts such as thinking and actions are considered as an act of reflective thinking."
Dewey (1933), as quoted in [5]	"Critical reflection is the active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends"
***Jacoby [5]	"The process of analyzing, reconsidering, and questioning one's experiences within a broad context of issues and content knowledge."

***Note: The instructors used this definition for the subject course.

Table A2. Catholic Social Teaching (CST) readings used in the course

Document	**Assigned Reading**	**Citation**
Gaudium Et Spes	§53-62, §63-72	Second Vatican Council, *Gaudium Et Spes* [Pastoral Constitution on the Church in the Modern World], Vatican Website, December 7, 1965, accessed August 26, 2016, http://www.vatican.va/archive/hist_councils/ii_vatican_council/documents/vat-ii_const_19651207_gaudium-et-spes_en.html.
Populorum Progressio	§6-21, §22-39 and §47-49	Paul VI, *Populorum Progressio* [On the Development of Peoples], Vatican Website, March 26, 1967, accessed August 26, 2016, http://w2.vatican.va/content/paul-vi/en/encyclicals/documents/hf_p-vi_enc_26031967_populorum.html.
Laborem Exercens	§24-27	John Paul II, *Laborem Exercens* [On Human Work], Vatican Website, September 14, 1981, accessed August 26, 2016, http://w2.vatican.va/content/john-paul-ii/en/encyclicals/documents/hf_jp-ii_enc_14091981_laborem-exercens.html
Sollicitudo Rei Socialis	§27-40	John Paul II, *Sollicitudo Rei Socialis* [The Social Concern of the Church], Vatican Website, December 30, 1987, accessed August 26, 2016, http://w2.vatican.va/content/john-paul-ii/en/encyclicals/documents/hf_jp-ii_enc_30121987_sollicitudo-rei-socialis.html

Table A2. Catholic Social Teaching (CST) readings used in the course (continued)

Caritas in Veritate	§1-9 and §53-63	Benedict XVI, *Caritas in veritate* [On Integral Human Development in Charity and Truth], Vatican Website, June 29, 2009, accessed August 26, 2016, http://www.vatican.va/holy_father/benedict_xvi/encyclicals/documents /hf_ben-xvi_enc_20090629_caritas-in-veritate_en.html.
Evangelii Gaudium	§1-9 and §177-208	Francis, *Evangelii Gaudium* [The Joy of the Gospel], Vatican Website, November 24, 2013, accessed August 26, 2016, http://w2.vatican.va/content/francesco/en/apost_exhortations/documents/papa-francesco_esortazione-ap_20131124_evangelii-gaudium.html
Bible	Matthew 5-7, Luke 6; Matthew 25:31-46, Luke 12:13-24, 16:19-31, 21:1-4; I Timothy 6:6-10, 17-19; James 2:1-9, 5:1-6; I John 3:11-24, 4:4-21	