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Development of a Pedagogical Model to Help Engineering Faculty Design Interdisciplinary Curricula

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The purpose of this study was to develop a model to help engineering faculty overcome the challenges they face when asked to design and implement interdisciplinary curricula. Researchers at a U.S. University worked with an Interdisciplinary Consultant Team and prepared a steering document with Guiding Principles and Essential Elements for the design, implementation, and evaluation of integrative curricula in engineering education. The team also developed exemplar materials (Integrative Learning Module) to provide a practical example and demonstrate how the tools provided could be used in the development of new curricula. The Guiding Principles, Essential Elements, and Integrative Learning Module were evaluated by faculty and students who provided feedback for their improvement. Faculty indicated that the tools provided were appropriate guidelines for faculty, but they indicated that the Integrative Learning Module was too long to be a manageable example. Students agreed about the need for more interactive, real-world applications of engineering concepts, but they expressed differences of opinion regarding how humanities and social sciences topics should be addressed in the engineering curriculum. Students who participated in a course modeling the Integrative Learning Module were satisfied with its use and learning outcomes. After the course, these students were able to explain the importance of problem definition, process, and disciplinary integration in engineering work.

Introduction and Literature Review

Higher education aims to prepare students to contribute to the design, implementation, and evaluation of responses to challenges such as climate change, global health, and hunger. To do that, graduates will need to demonstrate breadth and depth of knowledge in their discipline and competence analyzing, synthesizing, and integrating of knowledge and methods from several fields of study. The Accreditation Board for Engineering and Technology (ABET) criteria require that students have the ability to work in multidisciplinary teams, adopt professional and ethical responsibilities, and have the comprehensive education necessary to evaluate the impact of engineering solutions in a global, societal, environmental, and economic context (ABET, 2012). To meet these requirements, educators need to integrate elements from a broad spectrum of disciplines into the operational and formal dimensions of the curriculum (Navarro, 2004).

Interdisciplinary understanding refers to the integration of knowledge or thinking practices that produces a new form of understanding that would not be possible in a mono-disciplinary environment (Boix Mansilla & Duraising, 2007). Interdisciplinary teaching requires students to use new and prior knowledge from various disciplines and apply it to a real-world problem (Lattuca, Voigt, & Fath, 2004). Students learn to appreciate other disciplinary knowledge as essential to the practice in their fields (Nikitina, 2006). Most importantly, students learn how to conceptualize, evaluate, and synthesize disparate and ambiguous pieces of information and data in order to reach conclusions (Lattuca et al., 2004; Spelt, Biemans, Tobi, Luning, & Mulder, 2009). This integration is a dynamic process that occurs at different forms, levels, and intensities. Contextual integration uses the aspects of time, culture, and personal experience to show connections while conceptual integration uses concepts that span across disciplines (Nikitina, 2006; Wolff & Luckett, 2013).

Interdisciplinary courses in engineering education help students learn to critically evaluate disciplines in terms of their strengths and weaknesses (Orillion, 2009), transfer knowledge between disciplines, and analyze and evaluate the relationships between engineering, social sciences, the humanities, and the world in which they live. Through the analysis of different disciplinary data and perspectives, students learn to reflect, analyze, and evaluate all the information to formulate conclusions while still accepting that these conclusions are subject to change if new information arises (King & Kitchener, 2004). Interdisciplinary learning instructors are more likely to use active learning practices, authentic assessments, problem-based or project-based learning, and other teaching pedagogies that foster critical thinking and the use of other higher order thinking skills, which make courses more relevant to students, helps them develop deeper understanding, learn to apply knowledge to real-life problems, and see the ‘big picture’ (Czerniak, Weber, Sandman, & Ahern, 1999; Klein, 2005). Overall, an interdisciplinary curriculum environment uses certain theories and approaches that might improve learning (Lattuca et al., 2004), and it fosters a climate conducive to student sustained learning for meaning making, problem solving, reflection (Klein, 2005), and coping with complexity (Spelt et al., 2009).

The new K-12 "teaching to the test" apparent culture has resulted in a discipline-based parceled-out education where students memorize pieces of decontextualized information rather than practice critical thinking skills and learn to connect disciplinary knowledge and processes (Czerniak et al., 1999; Ruiz, Thornton, & Cuero, 2010). The climate is not much different in traditional higher education, which focuses on development of general skills and domain-specific content knowledge (Spelt et al., 2009). Hence, a common model of engineering education in the US is a curriculum constructed with a series of relatively independent discipline-based courses. Typically, students take their required engineering courses and choose some humanities electives to fulfill their general education requirements. One of the consequences of this practice is that students may perceive humanities courses as excess independent requirements to be "checkmarked" rather than important formative ingredients in their education (Arms, 1994), thus they do not take the time to reflect on their significance, application, or value. Further, many systems allow students to select humanities courses randomly or for scheduling convenience rather than strategically, further emphasizing student perception that humanities and social science requirements are unrelated to their discipline or their learning (Blewett, 1993). Similarly, some co-teaching efforts result in the same categorical thinking, for teachers divide and distribute responsibilities, and present their lessons and perspectives separately, as if they had been assigned separate mini-courses, rather than tasked to provide students with an integrated, team-based experience (Klein, 2005).

Traditional forms of higher education have been criticized for fragmenting education by fields of study and placing on the students the responsibility to transfer and integrate knowledge between disciplines without providing them with the tools to learn to do so (Clark & Wallace, 2015; Lattuca & Stark, 1994; Le Grange, 2011). Responses to this criticism range from models that envision universities completely restructuring their curriculum and concentrating on a small number of university-wide problem-based interdisciplinary programs to minor changes to some courses. Many suggest to continue college and department discipline-based programs and shift from students to instructors the responsibility for interdisciplinary teaching and learning. Thus, they recommend that all instructors include interdisciplinary learning objectives in their curriculum and modify course structure, content, and pedagogy accordingly. The problem is that many faculty are, or consider themselves, unprepared to do that (Bouwma-Gearhart, 2012; Justice, Rice, Roy, Hudspith, & Jenkins, 2009; Mattheis & Jensen, 2014; Stice, Felder, Woods, & Rugarcia, 2000).

Experience in the K-12 environment indicates that even in cases where teachers had positive attitudes toward integration, these attitudes did not materialize into practice (Czerniak et al., 1999). Reservations included lack of time for preparation, lack of time to devote to curriculum development, unfamiliarity with resources to support interdisciplinary teaching, and, most importantly, lack of teacher preparation: teachers do not know how to develop, implement, and evaluate interdisciplinary teaching and learning (Czerniak et al., 1999). Integrating interdisciplinary knowledge and processes into engineering courses and assessing student learning requires educators to have content knowledge in several disciplines, pedagogical knowledge, and pedagogical-content knowledge (Shulman, 1986; Tsang, 2000), all in an interdisciplinary context. In the higher education context, most STEM graduate programs lack formal pedagogical training for future faculty. In turn, many of them start their academic duties believing that their content expertise will be sufficient to ensure sound teaching, thus continuing the cycle of lecturing about content, focusing on memorization, and failing to engage students in the learning process (Bouwma-Gearhart, 2012; Mattheis & Jensen, 2014; Stice et al., 2000).

Recently, the Engineering Faculty of a US University adopted an academic plan to have adaptive curricula that provides students with a liberal education and incorporates social sciences and humanities disciplines [hereafter called humanities] throughout the engineering curriculum. The implementation of this plan required most faculty to revise their engineering courses to integrate interdisciplinary content knowledge and processes and to promote student interactions with faculty from multiple disciplines. Faculty who embarked in this endeavor faced many challenges, including questions regarding the selection of disciplines and topics that needed to be integrated into the engineering curriculum, the pedagogical models to adopt, the process to follow, and a plethora of practical questions about how to move from abstract ideas of curriculum change to the reality of design and their day-to-day teaching practice. This manuscript details the process followed to prepare a series of tools to support faculty their efforts to transform the curriculum.

Purpose and Objectives

The overall purpose of this project was to help engineering faculty overcome the challenges they face when developing interdisciplinary curricula. To accomplish this purpose, the following objectives were identified: a) develop guidelines (*Guiding Principles* and

Essential Elements) to help faculty in the design, development, implementation, and evaluation of interdisciplinary curricula in engineering education, b) develop exemplar materials (*Integrative Learning Module*) to demonstrate to faculty how the *Guiding Principles* and *Essential Elements* can be used in the development of interdisciplinary learning modules for engineering courses; c) engage faculty in a participatory evaluation to provide feedback for improvement of the *Guiding Principles*, *Essential Elements*, and *Integrative Learning Module*, and d) determine students' perceptions about the usefulness of the *Integrative Learning Module* to help them make connections between the humanities, social sciences, and engineering.

Methods

The project consisted in several objectives, each with its own methods. The lessons learned in each objective were used to improve the process and products from the other objectives. In essence, the guidelines (objective 1) helped develop the exemplar materials (objective 2), and the lessons learned while developing and using the exemplar materials helped improve the guidelines. This 'feedback' continued throughout the project. Furthermore, the data from faculty (objective 3) and student (objective 4) participation helped revise and enhance the guidelines (objective 1) and exemplar materials (objective 2). The research was approved by the researchers' University Institutional Review Board for research with human subjects.

Develop Guidelines for Interdisciplinary Curriculum Development

The researchers formed an Interdisciplinary Consultant Team of faculty in their university with expertise in community-based nutrition services, English, social work, international development, comparative literature, life sciences, health policy, art, education, and social issues in the workforce, and asked them to define the level of functional knowledge in their disciplines that engineering students needed to make connections between social sciences, the humanities, and engineering. The researchers had six 90-minute meetings with the Interdisciplinary Consultant Team over a year of collaboration. Based on the Team's discussions and recommendations, and research of the literature, the researchers developed a steering document with *Guiding Principles* to help faculty have the broad perspective needed to develop content for interdisciplinary course material (or curricula) and to help student integrate the humanities and engineering. This steering document also includes *Essential Elements* that guide students through their engagement with complex problems. The three parts of these *Essential Elements* are 1) process (the series of operations) that guides the student though the identification of the attributes that impact how the development of a solution is actually achieved; 2) analysis that prompts the student to analyze individual components (reductionism), as well as the interactions between those components (holistic perspective); and 3) activities that create the self-learning environment that leads to identifying the need for new knowledge and to eliminating misunderstandings. Details of these Guiding Principles and Essential Elements are presented in the results section of this manuscript.

Develop Exemplar Materials for Interdisciplinary Curriculum Development

Per recommendation of the Interdisciplinary Consultant Team, the researchers developed model materials that would serve as examples of how one could apply the *Guiding Principles* and *Essential Elements* in engineering education. One of these examples was a process-oriented *Integrative* (and interdisciplinary) *Learning Module*. The *Module* was created using a factual problem concerning water conservation and gray water use in the town where the *Module* was going to be implemented. The *Module* incorporated activities for the students that accounted for all five *Guiding Principles*, and they included many of the *Essential Elements* identified by the Interdisciplinary Consultant Team. The *Module* included activities for the students during which they were to collect a wide variety of data (including qualitative data from stakeholders) research the historical context of the problem, examine the cultural and societal implications of gray water use, and investigate policy issues. Key details about the *Module* are described in the results section of the manuscript.

Engage Faculty in a Participatory Evaluation

The *Guiding Principles*, *Essential Elements*, and *Integrative Learning Module* were presented to a group of engineering faculty who teach courses in agricultural engineering, biological engineering, and environmental engineering. Through a focus group model, these faculty were asked reflect on the process, provide feedback for improvement, and address the following questions:

- Would the *Guiding Principles* and *Essential Elements* be of help to them if they had to develop interdisciplinary curricula? What would they need to be able to use them?
- Did the *Integrative Learning Module* help them understand how to integrate the *Guiding*

Principles and *Essential Elements* into their courses?
- If the researchers were to provide faculty development, what kind of professional development would engineering instructors need (materials, examples, modules, etc.)?

The main objective of the faculty participatory evaluation was to determine if the *Guiding Principles*, *Essential Elements*, and *Integrative Learning Module* would be useful for faculty in their efforts to integrate the humanities and social sciences into their courses, and to determine other key resources that faculty may need to successfully transform their courses into interdisciplinary learning experiences for their students. Three of the researchers were present during the meetings with faculty, and all participated in the analysis of the data from faculty.

Determine Students' Perceptions about the *Integrative Learning Module*

To determine students' perceptions about the usefulness of the *Integrative Learning Module* to help them make connections between the humanities and engineering, the *Module* was used as a case study in a course taken by first semester first-year students majoring in agricultural engineering (Treatment Group). This course, titled Principles of Systems Engineering, is designed to introduce the basic tools used in systems engineering analysis, project planning, and management. Twenty-two students enrolled in this course volunteered to participate in this study and agreed to participate in focus group interviews. Students were divided in two interview groups consisting of 11 participants each to limit the number of students in each of the meetings. Smaller groups allowed for better group dynamics, allowed more time for all students to respond to questions, and established a more discussion-like atmosphere. There were no significant differences between the students in the groups. Two sessions of group interviews took place, one at the middle of the semester and one at the end of the semester. The interview protocol followed a semi-structured guide that focused on questions related to the students' reaction to the use of integrative learning processes and specifically the use of the *Module*. The interviews were audio-recorded, and transcribed for analysis. To assure student confidentiality, the focus groups were facilitated by a graduate student enrolled in a Ph.D. program in the University's College of Education, and the professor teaching the class did not know which students had participated in which interviews and was not given access to the interviews' recording. In addition, the transcripts were stripped of all names and individual-specific information. The interviewer did not participate in any of the classes and never discussed student responses with the professor. The second researcher analyzing the data was not teaching either of the courses and was not in the College of Engineering.

To provide a Control Group for this study, students enrolled in another course, Engineering Graphics and Design, were asked to participate in the study using the same interview protocol. The six students who volunteered to participate were also in their first year (first semester) at the University (same age as the students in the Treatment Group), were majoring in engineering disciplines other than agricultural engineering, and were not enrolled in Principles of System Engineering (the course using the *Module*). The Engineering Graphics and Design course focused on engineering visualization using the software AUTOCAD and had weekly sessions where engineers working in private companies made a seminar-style presentation concerning their job responsibilities. It is worth noting that most participants in all groups were males due to the higher enrollment of male students in engineering courses at the University.

The results from the focus groups are reported using the codes set for the audit trail, and they can be summarized as follows: a) Treatment Group participants interviewed in mid-semester were coded with prefix PET, b) Treatment Group participants interviewed at the end of the semester were coded with prefix POT, c) Control Group participated were coded with prefix CC, d) all participants were assigned a random number within their groups, and e) a letter was assigned to help locate the quote within the transcript document.

The data from the faculty and student focus group interviews were analyzed following guidelines proposed by Lincoln and Guba (1985) for analysis of qualitatively obtained data, including unitizing, categorizing, and filling in patterns. To establish trustworthiness, the researchers engaged in different techniques, including triangulation, process member checks, peer debriefing (credibility), and an audit trail (dependability and confirmability) (Lincoln & Guba, 1985). For triangulation, three researchers participated in the focus group meetings with faculty, and all of them participated in the analysis of data. For the student data, the Ph.D. student who conducted the interviews transcribed and analyzed the data, and a second researcher (who did not teach any of the classes) analyzed separately the data and compared the results between the two researchers. Regarding the member checks, after the analysis of the faculty data, the researchers shared the report with some of the faculty participating in the meeting and asked for feedback to check whether or not the conclusions reached by the researchers captured the essence of the interviews. One of the researchers also used a peer debriefer throughout the process (data collection, analysis, and reporting). In addition, detailed records were kept for the audit trail.

Results

Develop Guidelines for Interdisciplinary Curriculum Development

The Interdisciplinary Consultant Team was first asked to define the level of functional knowledge in their disciplines that students needed to make connections between social sciences, the humanities, and engineering. During the meetings with the Team, the following topics were discussed: a) the different perceptions of an issue; b) reflection, as a means to help students learn from experiences, success and failures, and as a basis for anticipating future occurrences; c) critical evaluation and dialogue among students in order to develop and share opposing points of view; and d) techne (Tabachnick, 2004) as related to viewing technology as an engagement, not an application, between science and domains of nature and society. These discussions led to the development of general philosophy and topic structure that the Team believed faculty should follow when integrating the humanities with engineering. This broad philosophy was then synthesized with the academic literature, particularly King and Kitchener (1994), Adams (2004), Wenk (2004) and Conlon (2008). As a result, the researchers prepared a steering document with the *Guiding Principles* for the design, development, implementation, and evaluation of interdisciplinary curricula in engineering education (Table 1) and the *Essential Elements* to ensure that engineering curricula integrate critical topics from other disciplines (Table 2). The *Essential Elements* include three parts—process, analysis, and activities—to help guide the students through their engagement with complex problems. The materials were broad enough to apply to any engineering course and to help faculty satisfy ABET criteria in new curriculum materials.

Develop Exemplar Materials for Interdisciplinary Curriculum Development

While the *Guiding Principles* and *Essential Elements* were prepared to help faculty transform curricula, the Interdisciplinary Consultant Team and the researchers believed it was necessary to also develop materials to demonstrate to faculty how the *Guiding Principles* and *Essential Elements* could be used. The Team suggested that the researchers illustrate the process through an example, which is an important step of supporting faculty in curricular change (Zhao, Witzig, Weaver, Adams, & Schmidt, 2012). The Team also suggested that for the example the researchers use a topic of current and local relevance so that the students could better contextualize the problem and interact with members of the community, as well as learn about and practice qualitative research methods. As a result, the researchers developed the Water Module, an *Integrative Learning Module*, based on the recycling of gray water in the town where the University is located. Thus, the *Module* was not developed for other faculty to use directly, but to provide an example of how to apply the steering documents when developing interdisciplinary curricula regardless of the issues chosen, local or global. In

Table 1
Guiding Principles for the Design, Development, Implementation, and Evaluation of Interdisciplinary Curricula in Engineering Education

Guiding Principle I.	Engineering must be viewed as a social process (Conlon, 2008) that is used to frame a problem, deals with social uncertainties and develops a range of potential solutions that could be of value to the target users
Guiding Principle II.	Engineering education should provide opportunities that transform students into professionals who can identify problems, recognize conditions and constraints and can realize the consequences of their actions.
Guiding Principle III.	Engineering education should guide students through a holistic course of inquiry; this course of inquiry should include reductionist roles of inquiry for deep understanding (Adams, 2004).
Guiding Principle IV.	Engineering education should cultivate reflection and critical thinking to individual and group environments (King & Kitchener, 1994)
Guiding Principle V.	Engineering education should view technology as an engagement, not application, between science and domains of society (Wenk, 2004).

Table 2
Essential Elements of Process, Analysis, and Activities to Ensure that Engineering Curricula Integrate Critical Topics from Other Disciplines

Essential Elements of Process

- Determine the social dimensions of the problem(s)
    - What are the operations of the social units (origins, evolutions, & uncertainties)
    - What are the interactions between social units and the patterns of these interactions
    - What are the historical events of the social units
- Consider the multiple dimensions of the social units
    - What are the multi-dimensional historic perspectives and conditions that affect problem
    - What are the diversity in ethics among the social units/populations
- Various conditions of problems
    - What are the conditions and potential conditions that affect future behavior, characteristics, & functions of a problem solution
    - What are the cultural, geographic, economic, etc. conditions
    - What are the various points of view & value judgment

Essential Elements of Analysis

- Holism & reductionism analysis must be done together
    - Determine the needs of the system and how each of these needs interact
    - Determine the needs of each domain within the system's and how each of these needs interact
    - Determine how to integrate the knowledge from each domain of the problem
    - Determine how to transfer knowledge among different domains
    - Determine the local and global patterns of the problem and solution
    - Define the measures that determine the solution effects on the system
    - Optimize the behavior of the individual components of the system
    - Optimize the behavior of the system
- Use of opposing views in problem evaluation
- Integration of knowledge of a problem and the constraints placed on the solution in order to optimize the solution
- Technology has consequences that should be anticipated & reduced or eliminated
- Technology should be viewed as an engagement not application

Essential Elements of Activities

- Students should use reflection of past experiences, successes, failures in order to anticipate future events
- Students should seek opposing views in problem evaluation process in order to better understand solution impacts
- Students should engage and evaluate of other students' work
- Encourage a critical dialogue among students

addition, the *Module* can be used as a model to a) create complementary opportunities in disparate disciplines inspiring new practices, b) explore new directions in curricula that will broaden engineering students' career opportunities, c) promote integration of engineering/technology subjects into humanities courses, and d) create rich formal/informal learning experiences integrating a variety of disciplines. In sum, since faculty may not have the opportunity for formal training in pedagogy or interdisciplinary teaching, the materials provided guidelines and an example for faculty to use, adapt, and implement in their own curriculum development, implementation, and evaluation efforts.

While initially the *Integrative Learning Module* was intended as an example, it was important to test its impact both for its continued improvement and for broader research purposes. When we first presented our research, the external evaluators (reviewers) asked that we assess the *Module* and its impact on students in our own course. In consequence, the *Module* was piloted in a Freshmen engineering course, and this manuscript presents both the process of developing the tools, and the evaluation of the tools by faculty and students.

The results and discussion section for objective 2 (develop exemplar materials) outlines the different components of the *Module* and explains how the five *Guiding Principles* connect to each component. The *Module* is based on state-wide and local water conservation plans (Barnes & Keyes, 2010) that were results of the "water war" between the states of Georgia, Alabama, and Florida (Hollis, 2009; Magnuson, 2009; U.S. Army Corps of Engineers, 1998) and the 2006-2009 severe drought in the southeastern USA. To implement portions of these plans, a northeastern Georgia town began to use a 4-tiered pricing system for the public, and local residents began to use gray water for landscape irrigation. If not properly treated, gray water can be detrimental to the environment and public health (Proceedings of Regional Science Workshop, 2010).

The *Module* focuses on objectives and needs associated with the problem statement, "*Design a system that allows safe gray water gardening that is acceptable for use at the typical single family residence in the University's town*." In class, the students were asked to explore the meaning of this statement as it relates to the needs of the residents of the University's town. The first set of assignments required the students to investigate the *social dimension* and the *multi-dimensional historic perspectives* of the *Module* by a) analyzing the impact past droughts had on living conditions, b) investigating how different social units consider the benefits of having a garden, c) determining if gardening is considered to be a recreational exercise or a means to supplement food sources, d) listing different cultural perspectives of the problem, and e) analyzing how these perspectives can influence future impacts of potential solutions. To do this, the students read a state-wide survey (Georgia Department of Natural Resources, 2003) and a local survey (Athens Grow Green Coalition, 2003) that were focused on the public's perspective of water resources and conservation. These students learned that Georgians are more concerned about water quality than quantity, that the majority of the local community believes the local government cannot manage water effectively, and that household conservation has a negligible impact on water resources.

The students were required to find *patterns of interactions of social units* that were affected by the problem. A sub-group of the class met with leaders of homeowners' associations who provided information concerning the local community's willingness to use gray water for outdoor irrigation and the features that they needed to encourage community participation in water conservation practices. These interviews led to students' discovery of a large and growing retirement community in the area that was willing to purchase a more expensive gray water treatment system if it meant little to no maintenance. Another student sub-group revealed a neighborhood with over 40% of the residents below the poverty level, where most of the households were not connected to a public water source. The students learned that the majority of people in this community believed that, given that they were not using the public water supply, it was unfair for them have to follow government mandates on water conservation.

Involving stakeholders early in the process, the students had to focus on *Guiding Principles* I, II and IV (Table 1) simultaneously. Comparing and contrasting the collected information helped students validate the people's concerns about unfair water conservation practices and analyze any patterns of usage (*Guiding Principle* III). Interviewing different social units required the students to participate in group environments, reflect on the opposing points of view and predict how a solution could impact future of the overall community (*Guiding Principle* IV). The assignments frequently included the reflection component of King and Kitchener's (1994) Reflective Judgment Mode, whereas when exposed to various perspectives of an environmental but social problem, reflective practice is essential throughout the entire process.

The students were required to explain the social constraints of gray water gardening particularly as it pertained to the local community. In the University's town, gardening often serves two purposes: one is focused on providing a supplemental food source, and the other is focused on emotional benefits (Armstrong, 2000; Mackay & Neill, 2010). Students had to examine both purposes and understand how these purposes related to the quality of life experienced by different social units. In addition, the students had to determine the types of plants grown by different social units, if these plants could be irrigated using gray water, and if the type of gardening used was economically feasible. These activities required students to examine the problem beyond the mere usage of gray water and to assess the impact of gardening on quality of life. Students investigated the different "beliefs" each social unit had about gardening and their different views toward water conservation (*Guiding Principle* II). Most importantly, students had to reflect on ethical issues (*Guiding Principle* IV) regarding food safety.

Students also had to consider and analyze the technical constraints of gray water systems; these constraints included the removal of large waste particles from water, the selection of filtering processes, the maintenance of these processes, and the need to incorporate natural rainfall runoff. Specific activities that the students attempted were to establish a) the best types of plants for treatment of waste water, b) water requirements for these plants, c) the amount of usable water rainfall provides in the area, d) the rate at which water could be applied to these plants, and e) the cost of materials and installation. These tasks involved the *Guiding Principles* III and IV by asking the students to determine a) the proper equations and scientific principles needed for analysis, b) the critical interfaces between the "solution" components and how the analysis of each component affects other components, and c) the patterns which exist between each step of the analysis and the iterations of these patterns. At the end of these activities, students reviewed each other's work, particularly when alternative solutions were considered.

One of the first activities to illustrate that social constraints and technical constraints are not isolated, students read editorials about public concerns on the technical aspects of gray water recycling. They learned, to their surprise, that plumbers in the area did not understand that gray water systems could not include other waste materials. Thus, students discovered a lack of adequate knowledge among plumbers about correct gray water use. Also, the students reviewed other systems marketed in the area, thereby benchmarking the successes and failures of conservation measures imposed on individuals and the impact that past water conservation practices have had on individuals, the community, and businesses.

Comparing students' solutions to case studies was necessary because the framework of the semester did not allow the students to fully design and then implement their solutions. The instructor provided case studies of gray water recycling experiments conducted in California (City of Los Angeles, 1992) and three other communities in the same state (Whitney, Bennett, Carvajal, & Prillwitz, 1999). Lectures were dedicated to comparing the students' local observations to published cases. Both reports provided excellent background information concerning eight test sites that included the household size and dwelling, topographic conditions, type of vegetation irrigated, and the type of gray water treatment system. The City of Los Angeles report (1992) discussed issues such as the quality of maintenance by homeowners, nuisance problems from mosquitoes and other animals visiting sites where the treatment system overflowed, and health related effects, as well as economic issues. The other report (Whitney at al., 1999) discussed the effects of gray water and its management on soil properties and water quality, such as soil microbial activity and nutrient levels in water.

Requiring students to compare their conceptual solutions to these issues helped them a) predict how the gray water treatment systems were used, b) consider intended and unintended outcomes of the students' suggested designs, c) engage in critical dialogues with other students, and d) compare each other's work and propose modifications to each other's solutions to the problem. These activities focused on *Guiding Principle* IV where reflection and critical dialogue bridge the gap between content learning and contextual learning to teach students to reevaluate a decision that might fulfill a technical need but does not fit with the characteristics, needs, and constraints of a community. These activities also relate to *Guiding Principle* V by asking the students to investigate the engagement between technology and society and how this interaction may result in unintended consequences. Consequences can be anticipated; however, no one can predict all potential consequences since people's interactions with technology are complex, varied, and uncertain. Referring back to *Guiding Principle I*, students were asked to learn to cope with uncertainties, asked to work iteratively, and asked to make continuous changes to their work so that their proposed solutions adapt to new knowledge and become more appropriate to the people and the communities affected.

Engage Faculty in a Participatory Evaluation

Key recommendations from faculty who reviewed the *Guiding Principles*, *Essential Elements*, and the *Integrative Learning Module* (the Water Module) are summarized in this section, supported by key representative quotes. Faculty members (FMs) emphasized the need to integrate the materials (rather than add new materials) into engineering courses so that the time devoted to essential technical knowledge was not sacrificed.

> FM 1: *"I think in most of my teaching, these would be nice goals to do, and there are ways that you could make either make them synergize with the rest of your course because the worst thing that I could do is fail to teach the technology."*

For some of the faculty the *Integrative Learning Module* was too complex and time consuming to use as a practical example (model) to help with their own curriculum development. Many indicated that if they were provided with smaller and shorter examples and models to follow, they most likely would be willing to develop their own and integrate them into their courses.

> FM 2: *"And realistically, if we're supposed to integrate these into a course like this, we can't spend the semester doing the whole thing, so certainly to use little smaller modules that could be incorporated"*

Faculty mentioned the importance of textbooks, written modules, workshops, webinars, and learning communities. Faculty also suggested to the researchers to consider guest lecturers and field trips to engineering workplaces in order to help students understand the connection between the humanities and engineering work. Furthermore, faculty expressed interest in professional development and teaching resources to help them integrate the *Guiding Principles* into their courses. Faculty also felt that integration was appropriate for certain courses, such as elective, gateway, design, and topics courses. These courses provide more flexibility in content covered, teaching methods, and evaluation of student learning. Faculty are more hesitant to change the curriculum (content, methods, evaluation) in upper-level, required, and "prescriptive" courses, or courses that are taught separately by several faculty (large enrollment, several sections, several instructors). Overall, they asserted that the *Module* was successful in integrating the *Guiding Principles* and *Essential Elements* into a course, and they agreed that the *Module* was comprehensive. However, they considered the *Module* too long and did not consider it feasible (time-wise and for continuity reasons) for them to use long integrative modules in their courses: they wanted a diverse set of shorter examples that were easier for them to adapt to their particular courses and engineering fields. Suggestions by faculty included that future efforts in this project should focus on creating a broader diversity of shorter examples.

Determine Students' Perceptions about the *Integrative Learning Module*

During the semi-structured interviews, students were asked their opinions about interdisciplinary courses and about the *Integrative Learning Module* (Water Module). Several students expressed an interest in taking interdisciplinary (integrated) classes. They felt that the humanities were not appropriately covered in the core curriculum, and they asserted that the humanities would be more relevant to them if they were integrated in the engineering curriculum.

> PETM5-b: *"I don't know how practical it would be, but to integrate it [social sciences and humanities] into every engineering class we take in our department would be pretty cool."*
> PETM5-c: *"[Integration] is doing exactly what we'd be doing as engineers as applying our sciences with our humanities and like if it's in the same class, you can easily see how it goes together."*

Another student acknowledged the need for "communications" courses. While the addition of courses does not necessarily imply separation, it is important to note that the student focus was on adding speech and communications courses rather than focusing on the need to integrate communication skills in engineering courses.

> PETM1-b: *"it'd probably pay off if you* ***added*** *[emphasis added] another speech and communications type class.*

Some students explained that they wanted to keep disciplines separate because that was the way they were comfortable with the curriculum, others because of the content density of engineering courses. Also, some students felt that learning the engineering content alone was already too challenging; thus, they preferred to learn different disciplines separately.

Students asserted that the *Integrative Learning Module* was a good example, was successful in connecting the humanities to engineering work, and helped them understand how engineering work is comprised of various social aspects in conjunction with mathematical and scientific principles (interdisciplinary). Students also realized that social aspects and customers' needs and concerns must be included in the engineering design process.

> PETM2-e: *"Our time is used really efficiently. We have not wasted a minute to the minute we get there to the minute we go. I mean, he's always teaching us, showing the way, and giving us examples from the past and incorporating them into the course, so it's not just dry facts."*
> POTM13-a: *". . . as far as connecting to the humanities and seeing the bigger picture and the social side of things…this one [the course with the Integrative Module] has done the best job."*

Many students, however, were overwhelmed, if not lost. They would have preferred more step-by-step instructions and a smaller project that they could have tackled from beginning to end. These students, however, acknowledged that they had limited experience with taking courses, this was the first exposure they had about integration of the humanities and engineering, and they felt the knowledge gained from the course would serve as a foundation for future engineering courses.

> PETM3-h: *"It's really abstract like nothing to hold onto to and say oh that's how it applies or that makes sense to that, so."*
> POTM13-b: *"I think it needs to be something a lot smaller and that you can actually see the results of at the end of the semester."*

The focus group questions and dynamics in the focus group with the Control Group were somewhat different. These students were enrolled in the Engineering Graphics and Design course and were not exposed to the *Integrative Learning Module* (Treatment). While the focus group facilitator was able to ask students about interdisciplinarity and the integration of the humanities in engineering, there was not an opportunity to discuss the lessons learned from the *Module*. Control Group students acknowledged that the guest speakers to their course helped them understand that engineering skills extend beyond mathematical and scientific knowledge. Communication, however, was the only non-technical issue addressed by most of the guest speakers. While students in the Treatment group viewed interdisciplinarity very broadly and could provide many examples and justifications, the students in the control group had only one "interdisciplinary" perspective and could only mention that integration was important because communication was important. When asked specifically about the social aspects of engineering work, their responses were much more limited than the response with the Treatment Group.

> CCM34-a: *"I think a lot of times there's a misconception that you don't need to be able to communicate with people. . . . I think that's before someone decides to be an engineer, that needs to be oh, by the way, you can't not be able to talk"*
> CCM36-a: *"A lot of times when you're working on an engineering project, you may not be working on the entire project itself, you may be working on a small part. If you can't communicate that to your teammates, that part won't be done, and if that part isn't done, the whole project falls apart, and so, communication keeps it all together."*

Limitations of the Study

This study had several limitations. Foremost, our study is limited to our context and university, and there was a small number of students and faculty that were exposed to the *Integrative Learning Module* and who gave feedback about the *Guiding Principles*, *Essential Elements*, and the *Module.* Also, the student Control (not exposed to the *Module*) and Treatment Groups (exposed to the *Module*) were non-equivalent groups (students were not randomly assigned to groups). Demographically, all the students were similar (first year, first semester students), though Treatment Group students were in agricultural engineering while Control Group students were in other engineering majors. Further, the number of Control Group students interviewed was much smaller than the number of Treatment Group students. However, this study aims to provide an assessment of the potential usefulness of the tools presented in the manuscript (*Guiding Principles*, *Essential Elements*, and *Integrative Learning Module*) in our context, not a generalized statement of the impact of these tools. As more tools are developed (more examples), and more faculty use the guidelines and develop their own curriculum, we will be able to conduct additional studies and assess the impact on student learning and student ability to integrate engineering and other disciplines. While these limitations caution us from suggesting that the *Guiding Principles*, *Essential Elements*, and *Integrative Learning Module* should be used at a large scale, by no means do they invalidate the study.

Discussion and Conclusions

The need for curricular transformation and the value of interdisciplinary curricula in engineering education has been discussed by many scholars (Arms, 1994; Blewett, 1993; Boix Mansilla & Duraising, 2007; Klein, 2005; Lattuca et al., 2004; Nikitina, 2006). Even in cases where educators have positive attitudes toward integration, these attitudes do not materialize into practice mostly because of lack of teacher preparedness (Czerniak et al., 1999), and lack of materials available for educators to use as guidelines and practical models (Zhao et al., 2012). The overall purpose of this project was to help engineering faculty overcome the challenges they face when developing interdisciplinary curricula. The researchers developed *Guiding Principles* (Table 1) and *Essential Elements* (Table 2) to help faculty in the design, development, implementation, and evaluation of interdisciplinary curricula in engineering. Key ideas from the *Guiding Principles* include the following: a) engineering must be viewed as a social process (Conlon, 2008); b) engineering students should be able to identify problems, recognize condition and constraints, and realize the consequences of their actions; c) engineering education should cultivate a holistic course of inquiry, reflection, and critical thinking (Adams, 2004; King & Kitchener, 1994): and d) engineering education should view technology as an engagement, not application, between sciences and domains of society (Wenk, 2004). The *Essential Elements* included *Essential Elements* of process, analysis, and activities to ensure that engineering curricula integrate critical topics from other disciplines. Thus, this project provides faculty with tools to engage in interdisciplinary instruction without the need to undergo extensive formal training.

The researchers also developed exemplar materials to demonstrate to faculty how these *Guiding Principles* and *Essential Elements* could be used in the development of interdisciplinary learning modules for engineering courses. Faculty and student feedback was used to improve the *Guiding Principles*, *Essential Elements*, and exemplar materials. Integrative learning modules similar to the one initially proposed proved to be too thorough (long) for many of the engineering faculty consulted at the researcher's University. Smaller modules may be easier to integrate into existing courses. Nonetheless, the *Module* can be used as a guide in faculty development workshops where participants could create their own smaller modules while adhering to the philosophy of curriculum integration.

Students expressed differences of opinion regarding integration but overall were satisfied with the use of the *Integrative Learning Module*. Some students preferred separate courses in engineering and the humanities and social sciences while others wanted courses that integrate disciplines. Students all seemed to agree that they want more interactive, real-world applications of engineering concepts. Because these students were first year students, they were experiencing an integrative course during their first semester and had no prior experience with traditional methodologies for comparison.

Some students indicated that the *Integrative Learning Module* was a real-world example that helped them apply the knowledge they learned in other courses. Students were able to provide specific examples about this connection and were able to use the *Integrative Learning Module* as the prime example of this connection, denoting effectiveness of the *Module.* These students were also able to explain the importance of knowledge of the humanities and social sciences as they relate to engineering practice. The students understood that engineering was process-oriented and that properly defining the problem is essential to engineering work.

Integrative modules may also enhance student understanding of interdisciplinary processes in other disciplines where science-based and humanities-based knowledge is essential, such as health, medicine, business, and technology. For example, human behavior and cultural beliefs impact medical treatment decisions that determine the success of a medical advancement within a population. Merely formulating an effective medical treatment is insufficient in improving population health outcomes; therefore, student learning about broader, interdisciplinary research methods that examine problems holistically are imperative. The *Integrative Learning Module* presented in this manuscript was prepared for engineering faculty. While the *Module* or broader interdisciplinary modules may be appropriate across multiple disciplines, it may be easier for faculty to work with examples from their own disciplines: adoption of innovations and transfer of knowledge is easier if the examples are compatible and close to learner's past experiences and prior knowledge (Rogers, 2003). Thus, we believe that while the *Guiding Principles* and *Essential Elements* are applicable to other disciplines, the examples – designed to facilitate faculty's job – are best if the key problem is familiar to the end user.

The next step of this project is to enhance and continue implementing the *Module* as we teach again the course that served as the "Treatment Course," develop more diverse and smaller examples for faculty to use as guides for the development of their own integrative learning modules, work with faculty as they implement their new curriculum, and continue assessing student learning and student ability to integrate engineering and other disciplines. At the time this manuscript is submitted, the researchers have implemented variations of the *Integrative Learning Module* in a freshman engineering course and a sophomore/junior engineering course, and they are in the process of analyzing quantitative data measuring student learning and interdisciplinary analysis and evaluation. The results of these additional implementations will be reported in new manuscript submissions. Differences in learning outcomes and sustained learning may be more apparent as students develop their own projects in their junior and senior years. We will continue to check the transferability and impact of these examples as faculty revise and adapt them or develop their own. Therefore, more long-term outcomes analysis is needed to determine if the *Guiding Principles*, *Essential Elements*, and integrative learning modules and examples are successful in supporting faculty in their curriculum development efforts, and in promoting student interdisciplinary learning; likewise, we will need to compare our outcomes to those programs not using integrative learning modules to make interdisciplinary connections. To date, the objectives of the project have been realized: we have guidelines and an example to help faculty in the design, development, implementation, and evaluation of interdisciplinary curricula in engineering education. These tools have been we have tested in a course with positive reception by the students who also provided valuable information to continue improving our materials, and we have a group of faculty interested in using the tools we are providing to support their curriculum development efforts.

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