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A Case Study of a Co-instructed Multidisciplinary Senior Capstone Project in Sustainability

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ABSTRACT

As societal challenges involving sustainable development increase, the need to effectively integrate this inherently multidisciplinary topic into existing curricula becomes more pressing. Multidisciplinary, team-taught, project-based instruction has shown effectiveness in teaching teamwork, communication, and life-long learning skills, and appreciation for other disciplines. Unfortunately, this instruction mode has not been widely adopted, largely due to its resource-intensiveness. Our proposed co-instruction model of multidisciplinary senior project administration was tested to see if it could effectively teach sustainability topics and duplicate the known benefits of team-taught instruction, while overcoming its resource-intensiveness. A case study of a co-instructed senior project was undertaken with students and faculty from electrical and mechanical engineering, business, political science, and industrial design. The participating students were compared to the control group, i.e. students who chose to complete a traditional disciplinary senior project instead. Extensive assessment was performed with pre/post quizzes, online surveys, focus groups, and course deliverables. The multidisciplinary projects outperformed traditional senior projects in 4 out of the 5 participating courses. However, the students in the multidisciplinary project rated their satisfaction with the experience lower on average than the control group. A strong, positive correlation between students' project satisfaction and rating of other instruction aspects ($0.50 < r < 0.7$, $p < 0.01$) was discovered, which has implications for all project-based instruction. Participating faculty generally found the process illuminating and engaged in scholarship and creative endeavors as a result.

Key Words: team-teaching, multidisciplinary instruction, capstone project

INTRODUCTION

As new skills are required of engineering graduates to respond to ever-changing societal needs, research on engineering learning systems is required to effectively adapt and respond to those needs. "Technical and non-technical fields are becoming increasing and inextricably linked" [1], and there is a need to incorporate more multidisciplinarity, teamwork, and communication skills, as well as a basic knowledge of sustainability topics into curricula that are largely segmented by discipline in many universities. In this paper, the term "multidisciplinary" will simply mean "more than one discipline," without a clear distinction between terms such as "interdisciplinary," "cross-disciplinary" and "trans-disciplinary".

The need to integrate knowledge of sustainability into engineering and other curricula is evidenced by the number of relevant federal funding opportunities for this purpose [2–5]. The study of sustainability is inherently multidisciplinary and requires a multidisciplinary approach, including considerations from economics (e.g. cost-effectiveness, return on investment), psychology (e.g. behavioral science), ethics (e.g. social justice) and management skills (e.g. leadership, organizational management), in addition to engineering and technology [6–7]. Furthermore, this approach is in line with the recommendations of the National Science Board and ABET, Inc. [8–9] for engineering curricula.

There are many examples of multidisciplinary, team-taught design courses and projects pertaining to sustainability-related topics in the prior engineering education literature both in freshman cornerstone courses [10–12] as well as at the upper-division level [13–23]. Educational benefits to this approach are consistently cited, including increased teamwork, communication, and lifelong learning skills, exceptionally prepared engineering graduates, increased appreciation for other disciplines, and better projects as evaluated by outside experts and/or project sponsors. In addition, it enhances retention and in some cases, attracts women and other groups that contribute to diversity [24–25].

Despite its overwhelming benefits, however, the barriers to successfully implementing this instruction mode are also consistently reported in the literature. The teaching approach is resource-intensive for the faculty and university administration [11, 14, 16, 26]. Finding an action-oriented team capable of working together for the requisite period of time is difficult [26]. Differing disciplinary approaches, tools, vocabulary, and negotiation styles are potentially serious impediments that often require delicate resolution [27]. Additional roadblocks include power imbalances, divergent standards, or simply negative attitudes [28]. Lastly, implementing this kind of curricula is generally not valued or aligned with university reward systems [24, 29]. It is clear that these barriers must be overcome before the cited benefits can be realized in a broad and systematic way.

This paper is structured as follows. The next section describes the co-instruction model adopted and studied in this work. Although the co-instruction model does not tackle all of the cited barriers to multidisciplinary project-based co-taught instruction, it is specifically designed to work within existing curricula and overcome the resource-intensiveness of initiating new required courses. This can be of particular concern to large public teaching universities with limited resources, packed curricula, contractual teaching loads, and enrollment targets. T;he third section discusses the research design that we employed and the fourth section presents an analysis and discussion of the results. The concluding section evaluates the implications of our experience for future multidisciplinary projects.

DESCRIPTION OF CO-INSTRUCTION MODEL

In this work, a case study was undertaken of a novel co-instruction model of administering multidisciplinary senior capstone projects. The objectives of this model include: integrating sustainability content in engineering (and other) curricula; duplicating educational benefits of multidisciplinary, team-taught, project-based instruction; and overcoming cited barriers in the prior literature.

In prior team-taught project-based instruction at our institution and elsewhere [13–24], there is typically a dedicated course and class space in which students from different disciplines can enroll and meet. It is common to have between 15 and 30 students total in the course, and between two and four instructors. Despite its educational effectiveness, the long term viability of this arrangement, especially in large public teaching universities, is unfortunately tied to its ability to support its resource-intensiveness. The student-to-faculty ratios are very small, the faculty contact hours are high for the given amount of teaching credit, and requiring additional courses on top of already packed curricula is difficult.

The co-instruction model of multidisciplinary senior project instruction was designed based on these considerations and tested at San Jose State University (SJSU) in the 2010–2011 academic year. Instead of a dedicated course, the co-instruction model required that a set of relevant project courses spanning the desired topics be scheduled at a common time slot. In doing so, the courses had the capability of meeting jointly, separately, or in subsets, allowing cross-disciplinary instruction and interaction, while simultaneously preserving autonomy, flexibility, and programmatic learning outcomes for each course instructor. Joint meeting times were used for lectures covering terminology and sustainability from each of the disciplinary perspectives, co-supervision of project activities, and integration of subprojects. Plenary session times were used for in-depth discussion of disciplinary considerations appropriate for students of the corresponding major. Meetings between subsets of the participating courses could be used as needed to address corresponding interrelated issues and design problems. Online collaboration and communication tools were used to facilitate information exchange between the non-co-located groups. It was the hope that shared facilities, resources, and supervision would overcome, or at least offset, increased time and resources required for coordination and collaboration.

In conjunction with the common class time slot, appropriate projects with disciplinary subprojects needed to be identified. Each disciplinary subproject had to be of sufficient scope to handle a similar-sized student team compared to traditional class projects. Although this introduced the challenge of managing large multidisciplinary projects, it did not increase the project-supervision load of the instructors.

This work sought to establish self-managed teams of students and faculty as opposed to a hierarchical style. Self-managed teams are described in prior literature as promoting factors leading to global competitiveness, autonomy, and intrinsic motivation [22]. The co-instruction model with joint and plenary meetings and common project aimed to foster the necessary elements for the success of self-managed teams, including: sufficiently high prior knowledge, general understanding and appreciation of disciplines outside one's own, shared vision and goals, and strong affinity towards them [22].

For this study, between five and seven students from each of the five courses participated in the multidisciplinary joint project in sustainability; the remaining students were instructed in the traditional manner. The participating courses were: (1) electrical engineering senior design project, (2) mechanical engineering senior design project, (3) industrial design senior project, (4) green entrepreneurship, and (5) public policy. All five courses required a group project as a significant fraction of the course grade. (The students instructed in the traditional manner also did a project in sustainability, albeit in a disciplinary context. The engineering capstone courses do so to align with accreditation requirements. The industrial design projects consider life cycle analysis. The green entrepreneurship course obviously addresses sustainability, and energy policy is required in the public policy course. All projects undertaken in the five courses are listed in Appendix A.)

The joint multidisciplinary student project was a zero-emissions house (dubbed ZEM House), a 100-square-ft demonstration house that emits no greenhouse gases during operation. The students working on the ZEM house are subsequently referred to as the ZEM students in this paper. The 100-square-ft footprint was a practical, self-imposed constraint to increase options for campus build sites. Otherwise the ZEM students were instructed to determine why, what, and how they would design and build the structure. The design of the house took place in the fall semester with students from all five disciplines. The build and test of the house took place the subsequent spring semester with the three senior project courses, all of which required a prototype for their class deliverables. The business and public policy courses only required a design, and consequently the ZEM students from those courses were not required to participate in the spring. The ZEM House project was initially broken down into subprojects covering public policy, HVAC/structure, economic feasibility, user needs, and the photovoltaic energy system, and preliminarily assigned among the five participating disciplines as listed in Table 1. All five disciplines were expected to contribute their expertise and influence the design of the ZEM house.

Several changes and corrections were made to the multidisciplinary project in response to formative assessments. In the summer prior to the launch, the five instructors met to plan the five disciplinary lectures covering sustainability perspectives and terminology. The key topics in each lecture were largely selected by the faculty member in that area and are listed in Appendix B. Based on feedback, the lectures were altered in an attempt to cater the presentations and learning towards students outside of the engineering discipline. During the fall semester, some miscommunications occurred during group interactions and in the online discussion board, resulting largely from differences in communication styles and culture between the different disciplines. As a result, guidelines for communicating content, particularly in the online forums, were authored and posted for the group in an effort to define and observe etiquette. In addition, the large multidisciplinary student group appeared to have difficulty meeting on a regular basis outside of the regular class period. In response, a team liaison structure was established, where one student liaison from each disciplinary team was responsible for meeting weekly and communicating the results of the meeting to his/her

Mechanical engineering	HVAC, structure
Electrical engineering	Solar PV and electrical system, lighting
Industrial design	Human factors, material selection, aesthetics
Political science	Public policy, energy policy, and global warming
Business	Economic analysis, entrepreneurial opportunities

Table 1. Subprojects by discipline for the SJSU ZEM House, 2010–2011.

disciplinary team. The additional guidelines given to the ZEM students mid-semester in Fall 2010 are shown in Appendix C. In the spring semester, the online collaboration tool, Desire2Learn, was replaced by Basecamp, in response to students' feedback indicating a need for a more functional and easier to use online collaboration environment. Also, it appeared that the team liaison structure was not successful at filtering information through the group as intended. Hence, it was disbanded and replaced by monthly group meetings involving all students and instructors. In addition, the spring semester instructors scheduled weekly teleconferences to touch base and to attempt to jointly head off any crises that might be brewing.

A detailed description and the results of the fall semester design phase of the multidisciplinary project are documented in a prior publication [30]. Further analysis of the design phase and additional results from the build and test phase are comprehensively described in the current work.

RESEARCH DESIGN

Assessment of the co-instruction model pilot was performed using a mixed methods approach involving quantitative and qualitative data. The instruments used in the study are listed and briefly described below. They were administered to all students in the five participating courses, unless otherwise indicated.

- Pre/post quizzes: A multiple choice quiz covering content from the five disciplinary lectures on sustainability perspectives, administered before and after the fall semester.
- Personality test: A ten-item test [31] for the well-regarded Big Five model of personality [32] was (extraversion, agreeableness, conscientiousness, emotional stability, and openness), administered at the start of fall semester.
- Online student surveys: Multiple choice and Likert scale questions covering course assessment, self-assessment of learning, teamwork, attitudes towards multidisciplinarity and sustainability, and learning preferences, administered at the end of fall semester. A modified version was administered to the three participating senior design courses at the end of spring semester.
- Focus groups: Open-ended questions to obtain detail on the online student survey questions, administered to the ZEM students, at the end of fall semester. The scheduled spring semester focus group did not garner enough participation to warrant the evaluator's time.
- Instructor interviews: Open-ended questions to obtain instructors' perspectives, challenges, and rewards, administered at the conclusion of all five instructors' participation in the project instruction.

In addition, direct artifacts of student activity and achievement, such as scores on project deliverables, activities and contests entered, press articles, meeting minutes, and participation in online forums were available for the analysis and assessment.

There were a total of 28 students in the ZEM group, and a total of 115 students in the five combined courses including the ZEM students. The non-ZEM group, i.e. students who chose to do a traditional class project, formed an adequately large control group for use in our study to assess the effect of the multidisciplinary co-instruction model. In addition, comparisons between disciplines were made, where helpful, in interpreting the results.

Statistical analysis was performed with IBM SPSS Statistics, Version 19. A standard t-test was generally used to judge if there were significant differences between the means from two groups, except in the analysis of the pre-post quiz scores, which were analyzed using a common ANCOVA approach described in the text. The effect size, EF, was reported as the difference in means divided by the standard deviation of the control group. A one-way ANOVA procedure in conjunction with post-hoc tests were used to determine if there were any significant differences in means between more than two groups. Pearson's correlation coefficient was computed to evaluate the strength of associations between dependent and independent variables. The probability-value, i.e. p-value, was used to judge statistical significance, with a p-value < 0.05 judged to be significantly small to rule out the null hypothesis (unless otherwise specified), as is conventionally interpreted.

Informed consent and confidentiality of the participants were implemented for this study, in compliance with the Institutional Review Board (IRB) at our institution. Student IDs were collected, and hence we had access to their GPA, major, year in school, ethnicity, and gender.

RESULTS AND DISCUSSION

An extensive case study was conducted of the co-instruction model for administering multidisciplinary senior projects in sustainability. Student characteristics, evidence of educational effectiveness, as well as lessons learned (i.e. things that didn't work as expected) are reported in this section.

Classes/Disciplines Involved.

Again, the participating courses in the pilot co-instruction model were: (1) electrical engineering senior design project, (2) mechanical engineering senior design project, (3) industrial design senior project, (4) green entrepreneurship, and (5) public policy. The three senior design project classes are required, two-semester, culminating experience courses, and are exclusively composed of seniors of that major. The green entrepreneurship and public policy courses, on the other hand, are one-semester elective courses for majors or minors in business or political science, respectively. The minors are both open to students of all majors, although each tends to draw upperclassmen from a subset of the university population (i.e. the business minor attracts majors from numerous disciplines, and the political science minor draws primarily from education, social sciences, and the humanities). In addition, the students in the elective courses are not necessarily seniors at the end of their course of study.

The disparate nature and composition of the participating courses illustrates the flexibility inherent in the co-instruction model.

ZEM vs. Non-ZEM

The ZEM and non-ZEM student groups were largely voluntary and self-selecting. Traditionally, students pick the project they wish to work on, and all available projects are typically staffed with minimal negotiation. In two of the courses (mechanical engineering and public policy), more students showed interest in the ZEM project than the available spots, and some minimal selection by the instructors was required. In the remaining three courses, student participation on the pilot project was entirely voluntary and uncontested.

The ZEM students were male-dominated, with 22% women and 78% men [30]. The gender composition of the ZEM team mirrored the gender composition of the participating courses as a whole. All of the courses, except public policy, were comprised of between 4% to 29% women. The public policy course, however, had 62% women.

Statistically significant differences in GPA existed between the ZEM and non-ZEM groups. The GPAs were pulled from their records during Fall 2010, and do not reflect the grades received in the participating courses in this study. The average GPAs of the ZEM and non-ZEM students were 3.2 and 2.9, respectively, with a p-value of 0.007. GPA is one indication of ability, and is considered in the interpretation of performance results.

Lastly, ZEM students were more open to new experiences, more extraverted and more emotionally stable compared to the non-ZEM students. The mean values for all five personality domains, scored between 0 and 7, with higher scores indicating stronger tendencies (e.g., more extraverted, more agreeable), as well as the p-values for an ANOVA test are listed in Table 2.

Learning Preferences

An important difference in learning preferences between subgroups of students was discovered. Students were asked to indicate their degree of agreement on a five-point scale (1=completely disagree to 5=completely agree) with eight statements probing their preference for multidisciplinary courses, project-based learning, group work, reading, and discussion.

There were no statistically significant differences in learning preferences between the ZEM and non-ZEM groups.

	ZEM N = 26	Non-ZEM N = 77	p-value
Extraversion	**4.92 (SD = 1.20)**	**4.35 (SD = 1.20)**	**0.04**
Agreeableness	5.10 (SD = 1.04)	4.86 (SD = 1.12)	0.34
Conscientiousness	6.00 (SD = 1.07)	5.57 (SD = 1.22)	0.11
Emotional Stability	**5.85 (SD = 1.26)**	**5.27 (SD = 1.19)**	**0.05**
Openness	**6.25 (SD = 0.74)**	**5.49 (SD = 1.04)**	**0.001**

Table 2. Mean personality scores for ZEM and Non-ZEM students using the Big-Five personality domains.

However, there was a difference in learning style preferences among the disciplines. Statistically significant differences in responses by discipline based on the participating courses are shown in Table 3. The ANOVA p-value of 0.00 indicates that there were significant differences between one or more of the subgroups.

A series of post-hoc tests comparing each subgroup with each of the others revealed that the political science students in our study were significantly less interested in project-based classes than traditional lecture-style classes compared to students in electrical engineering, mechanical engineering, and industrial design. (Business students had similar numbers to electrical engineering, mechanical engineering, and industrial design, but were not statistically different, strictly speaking, than political science, possibly due to the small number of business students who filled out this portion of the survey. Industrial design students had the highest mean response compared to the other groups, but the differences were not statistically significant.) The political science curriculum is more reading- and writing-intensive compared to the others, and the students have less familiarity with group work and project-based instruction. Proclivities towards or familiarity with various learning preferences likely exist between disciplines in general, and should be accounted for in the design of multidisciplinary project-based experiences.

	Mean level of agreement (0–5)					
Statement	**EE N = 22**	**ME N = 26**	**ID N = 20**	**BUS N = 9**	**PolSci N = 23**	**ANOVA p-value**
Project-based classes are more interesting than traditional lecture-style classes.	3.95	4.07	4.68	4.11	**3.13**	0.00

Table 3. Statistically significant difference in learning preferences by discipline/course.

Effectiveness of Disciplinary Lectures

The five disciplinary lectures at the start of fall semester delivered to the ZEM students ranged from 30 to 50 minutes each, and were intended to impart a general understanding for the five subjects to the students working on the multidisciplinary project. The performance of the ZEM and non-ZEM students on the pre/post quizzes were analyzed to determine if this purpose was accomplished. For this analysis, students who did not complete both the pre- and post-tests filled out in their entirety were dropped to exclude non-serious entries.

The non-ZEM students did not receive this formal instruction, but instead were required to do more self-directed research on an as-needed basis to pick up relevant knowledge outside of their own discipline, as is typical for these sorts of capstone projects. They were not expected to pick up the range of topics in the multidisciplinary lectures on sustainability, but instead provided a benchmark for quantifying how much multidisciplinarity is picked up in the typical course of more traditional disciplinary project-based instruction.

Both ZEM and non-ZEM students improved from pre-test to post-test, as found by paired sample t-tests, but to determine whether ZEM students improved more required additional analyses.

ZEM students and non-ZEM students had similar scores on the pre-test. The average scores on the pre-test were 12.0 and 13.0 points (out of 25) for the non-ZEM and ZEM students, respectively, but this difference was not statistically significant ($p = 0.15$, $EF = 0.35$). However, the ZEM students scored significantly higher on the post-test (14.9 points) than non-ZEM students (12.9 points), with $p = 0.004$ and $EF = 0.58$. It was possible that these results were affected by academic ability (i.e the ZEM group had a higher average GPA than the non-ZEM group). To check this, we ran an ANCOVA, with the dependent variable being pre-post change scores, and the covariates being GPA and pre-test scores (to control for initial performance). This analysis showed that when controlling for GPA and pre-test scores, the ZEM v. non-ZEM comparison approached significance, $p = 0.07$. Interestingly, GPA was not a significant predictor of improvement in the model tested.

ZEM-related improvements on the post-test was largely due to increases on the electrical engineering and entrepreneurship portions of the test. ZEM post-test scores on those portions were significantly higher than non-ZEM scores, with $p = 0.05$ and 0.005, respectively.

Based on the pre/post quiz data, it appeared that the disciplinary lectures had some limited benefits on knowledge acquisition. However, this does not change the result that the average score on the post-test for the ZEM students corresponds to a percentage of 60%, which is hardly impressive.

The comments made by the ZEM students during the fall focus groups indicate limited benefit of the lectures. Representative remarks regarding the lectures include the following:

"I thought the joint meetings could be better if we could talk to each other instead of just having a lecture."

"I mean the broad overview of the lectures, they were almost, I hate to say they were kind of pointless. We did not, I mean you can just learn that from general pick up the newspaper essentially and of your core classes you get a lot of the basics there."

"The Wednesday lectures, [. . .] I don't think that they had a very – they did a very good job of preparing us like giving us the tools to communicate between disciplines."

These comments indicate that the lectures were viewed as too simplistic by many students. However, the average post-test score for the ZEM students indicate lack of understanding and information retention rather than content that was too easy.

Student Rating of Instruction

In an unexpected finding, the ZEM students rated their instruction lower than the non- ZEM students in many categories, particularly in the fall semester. We offer a hypothesis to explain this result, and present ramifications for all project-based instruction.

Students in all five courses were asked to rate the quality and helpfulness of the seven following aspects of their instruction: lectures, course format, faculty supervision, peer interaction, online resources, other resources, and grading. The possible responses for each were: (1) NA, (2) poor, (3) fair, (4) good, and (5) excellent. All responses of (1) NA for any of the items were excluded from the mean. Quality-related and helpfulness-related items were averaged to form two different scales, and each scale showed adequate internal reliability ($\alpha > .82$ for all scales), indicating that they are highly reliable reflections of the individual components. These scales were calculated for both fall and spring semesters and are summarized in Table 4. Statistically significant differences between groups and the control group (i.e. the Non-ZEM students) are indicated in bold.

As shown in Table 4, the ZEM students rated their instruction quality and helpfulness significantly lower than the non-ZEM students in the fall semester. This is a surprising result, because the ZEM students received all of the traditional course instruction in addition to the extra instruction from the multidisciplinary activities, yet were less satisfied with it as a whole. The same trend was not found in the spring semester, where the differences between the ZEM and non-ZEM students were not significant from a statistical standpoint.

There were discrepancies between the ratings from the engineering students on the ZEM project compared to the non-engineering students, also shown in Table 4. In general, the ZEM averages for

	Cronbach's α	Non-ZEM N = 76 (F10) N = 30 (S11)	ZEM N = 23 (F10) N = 12 (S11)	p-value	ZEM-ENG N = 10 (F10) N = 7 (S11)	p-value
Instruction Quality (Fall 10)	0.908	**3.97**	**3.54**	**0.01**	3.83	0.56
Instruction Helpfulness (Fall 10)	0.909	**3.91**	**3.29**	**0.00**	**3.40**	**0.03**
Instruction Quality (Spring 11)	0.818	3.78	3.59	0.41	3.97	0.47
Instruction Helpfulness (Spring 11)	0.863	3.64	3.48	0.51	3.93	0.33

Table 4. Instruction quality and helpfulness as rated by Non-ZEM (control group), ZEM, and ZEM-engineering students.

the engineering students for instruction quality and helpfulness were higher than the non-engineering students in the ZEM project for both semesters, and statistically the same as the Non-ZEM control group, with the exception of Instruction Helpfulness in the fall semester.

Why the discrepancy, even within the same project? Upon closer examination of all data, it appears that project experience varied greatly from team to team, and even in some cases within the same team. The authors hypothesize that the project experience tied together instruction activities and thus strongly influenced student rating of instruction. In other words, students who had a bad project experience tended to rate all other aspects of the course poorly. The flip side was also true – students who had a positive project experience tended to rate all aspects of the course highly. The dependence of the student evaluations on project experience was informally observed in a smaller prior study [33], but without the sample size necessary to conduct the proper analysis. In the current data set, all students were asked to rate their satisfaction with their project experience on a Likert scale between (1) not at all satisfied, and (5) extremely satisfied. To test our hypothesis, the Pearson's correlation coefficient was computed using students' answer to this question, and each aspect of instruction for which they rated quality and helpfulness. The results are summarized for both semesters in Table 5.

	Project Satisfaction Fall 10	p-value	Project Satisfaction Spring 11	p-value
Instruction Quality (Fall 10)	**0.52**	**0.00**		
Instruction Helpfulness (Fall 10)	**0.59**	**0.00**		
Instruction Quality (Spring 11)			**0.70**	**0.00**
Instruction Helpfulness (Spring 11)			**0.50**	**0.001**

Table 5. Pearson's correlation coefficient between students' project satisfaction and instruction quality/helpfulness (statistically significant correlations in bold).

As Table 5 shows, students' project satisfaction was strongly and positively correlated ($0.50 < r < 0.70$) to all surveyed aspects of instruction quality and helpfulness in both semesters, and these associations were significant ($p < 0.001$). Although correlations do not imply causal relationships, these calculations provide evidence that the dependence of student evaluations on project experience may exist. It is unclear whether this might happen because the intended integrative learning fails with bad project experiences and consequent appreciation of instruction is not gained, or if disgruntled students simply rate instruction as poor as a continuation of their frustration.

The ZEM students, on average, rated their project satisfaction below the non-ZEM students in both semesters. This, in part, explains why the rating of their instruction was lower than the control group. Comments from the fall focus group and open-ended questions on the online survey reveal challenges in coordinating, communicating, and decision-making.

> ". . . it was very fragmented and I think that is one of the challenges in this project and real life is that groups are fragmented and also they have different languages and stuff."

> ". . . we had never milestones or assignments where we were forced to share information. [. . .] Like the teacher was not giving them credit for it and it takes a long time to share information so it is like I don't have all that time and I'm not getting a grade for sharing information with you."

> "I think the deadlines were not lined up for all the classes, all the different groups. [. . .] I don't think [the instructors] did communicate when those things would be due. We had a really hard time, we tried to organize that in the meeting . . ."

It appeared that there was some confusion in some of the ZEM sub-teams regarding the specific deliverables required in the other classes, leading to unrealistic expectations of what the other teams would deliver. These comments indicated a failure to acquire the administrative skills and/or a shared vision required for a self-managed team to be successful. One ZEM sub-team, in particular, rated its project experience far below the non-ZEM average in the spring semester. One student wrote:

> "I feel like I wasted much of my senior year on a project I cannot be proud of. [. . .] I would have been much better served by doing a normal project."

The ZEM engineering students rated their project experience about the same or a bit higher than the non-ZEM students in both semesters. Although they did also echo the frustrations of the rest of the ZEM group, they showed evidence of overcoming some of their preconceptions regarding multidisciplinarity, which they then appreciated:

> "Okay, well at first I was thinking that ZEM House would be concentrated on EE but after I got in, in the beginning I realized we are not just the major part we are just like a small portion of it. We have solar panels and stuff like that, I didn't realize how much business and political science got into it."

> ". . . the one benefit that I really like was like it was a challenge to like interpret [Industrial Design's] concept into something that we can actually build and I think at first I was kind of like a little mad about it, but then once I just kind of realized you know what, this is a really cool concept so we are the ones who have to figure out how to do it. And then I realized that really is the job of an engineer. So I thought that was a really good lesson for me to learn."

These comments indicated that some students were successful at gaining insight into the other disciplines and making connections to their own as a result of this experience. Whether this was a result of the subject of the multidisciplinary project or with the instruction and/or mentoring received by the ZEM engineering students was not known. Integration of knowledge is one of the hallmarks of multidisciplinary and interdisciplinary education [23], and these comments provide evidence that progress in this area was made by some of the students.

Overall, the challenges in managing and participating in a large, multidisciplinary project were substantial, and appeared to influence the ZEM students' rating of their instruction. The strong correlations discovered in this study have implications for all instructors using project-based learning, and underscores the importance of project supervision and mentoring relative to other classroom activities.

Student Self-Assessment

Students were asked to indicate their level of agreement with various statements probing their learning gains from their senior project experience. The average responses for both semesters are shown in Table 6. The responses correspond to (1) completely disagree/not at all confident, (2) somewhat disagree/slightly confident, (3) neutral/somewhat confident, (4) somewhat agree/very confident, and (5) completely agree/extremely confident.

As shown in Table 6, there were no statistically significant differences between the ZEM and non-ZEM student responses in either semester. Although many of the average scores for the non-ZEM students appeared to be higher than for the ZEM students, the differences can be attributable to

	Fall 10			Spring 11		
	ZEM N = 23	Non-ZEM N = 79	p-value	ZEM N = 12	Non-ZEM N = 30	p-value
Please rate your confidence in seeking collaboration and/or advice from someone outside your discipline	3.87	3.47	.091	3.42	3.57	0.672
I understand the role of my discipline in society better as a result of this experience.	3.91	3.90	.942	4.08	4.03	0.835
I understand the role of other disciplines in society better as a result of this experience.	3.78	3.71	.744	3.55	3.76	0.434
I am more enthusiastic about my discipline as a result of this experience.	3.65	3.88	.323	3.92	4.21	0.304
I am more interested in learning about other disciplines as a result of this experience.	3.91	3.67	.241	3.42	3.76	0.308
My communication skills have increased as a result of this experience.	3.48	3.89	.060	3.83	4.10	0.362
My teamwork skills have increased as a result of this experience.	3.74	4.04	.149	4.00	4.11	0.785
I am interested in working in fields related to sustainability upon graduation as a result of this experience.	3.39	3.82	.115	3.42	4.07	0.097

Table 6. Student self-assessment of confidence, understanding, and communication and teamwork skills.

chance variations alone, and cannot be interpreted as such with this particular data set. There were trends ($p < 0.10$) in the fall semester for the ZEM students to feel more confident than non-ZEM students about seeking help outside of their disciplines, and for ZEM students to feel their communication skills had improved less than the non-ZEM students, but both trends largely disappear in the spring semester. There is a very mild trend in the spring semester for ZEM students to be less interested in working in fields related to sustainability upon graduation. These results largely contradict much of the prior literature, which shows that multidisciplinary, project-based learning improves communication and teamwork skills, as well as an appreciation for one's own and other disciplines.

It is likely that the coordination and communication frustrations evident on the ZEM project also played a role in these results. In particular, there were provocative comments made about teamwork both between and within the sub-groups. There was a large amount of conflict on this project, particularly in the spring semester. Some of the ZEM students wrote the following (names have been removed to protect confidentiality):

> "I felt Student A and Student B would often make major decisions together when I was not present and didn't try to contact me to ask my input. I expressed my doubts [. . .], but the team did anyways, resulting in a poorly thought out "frankenstein" design."

"Student C became a dominant leader [. . .] who could not communicate effectively. There were times when Student C would simply make a statement to contradict my own as if his words were the law, but he would not take the time to explain himself. He was very subversive and undermining."

". . . we went way out left field because we had no idea you know and I think part of it was we had some communication breakdown from our liaison specifically. We didn't see her for like two weeks [. . .] it really cut us off even more."

Two of the instructors offer their insights:

". . . I think the other criticism [my students] felt was that they weren't respected [by the other disciplines]"

". . . my students [. . .] are just terrified of going into a situation and having to work with somebody from a discipline that was involved in this project because they did not come away with a good taste. That is not a good thing for our students to walk away with."

These comments indicated that the interpersonal and/or conflict resolution skills required for self-managed teams to be successful were not achieved. Conflict itself is not negative and results from differences in perspectives; its resolution often leads to better and more thoroughly vetted solutions [23]. More effective fostering of interpersonal and conflict resolution skills is required to overcome this roadblock in future renditions of the co-instruction model.

Direct Assessment of Project Outcomes.

Despite the difficulties with the project reported by the ZEM students, the overall achievement of the group as a whole was very positive, particularly in comparison to traditional undergraduate senior projects. Although the contributions from the disciplinary sub-teams varied, the influence of all participating disciplines was very much evident in the final design and prototype, to an extent that would not have been possible if each discipline had worked alone, described as follows.

In the fall semester of 2010, a number of activities were undertaken by the ZEM students, culminating in the design of the ZEM house. They organized an event to make a political statement [34, 35]. They entered and placed in a campus-wide innovation and entrepreneurship contest, and consequently presented their project at the Annual State of the Valley conference in February 2011, attended by over 1000 civic and business leaders. Such activities are never undertaken by traditional engineering senior projects (except for the occasional entry in an entrepreneurship contest), and very much reflect the influence of business and public policy. A design emerged incorporating a solar photovoltaic and battery storage system, heat pump and air conditioning, LED lighting with automatic dimming and motion control, passive lighting, and solar heating, and staging of the interior, which obviously reflect the contributions of engineering and industrial design. Furthermore, design elements reflecting building codes and aesthetics, such as outwardly angled walls for the appearance of spaciousness and the accessibility ramp, reflect the contributions of industrial design and public policy. Lastly, over $15K of donations were solicited from local companies to support the project, including solar photovoltaic panels, batteries, an inverter, charge controller, lumber, and windows. These activities were undertaken by ZEM students from all five disciplines.

In the spring semester, the senior project ZEM students built and tested the ZEM house design from the previous semester. The first nail was hammered on 3/1/11 and it was finished, minus the interior staging, on 5/1/11. The sheer scale of fabrication and testing required for this project far exceeds a typical engineering or industrial design senior project, and its completion and successful operation is a credit to the students. As one instructor wrote, "it's a testament to their dedication and commitment to getting the job done."

In addition, the project was featured in Sustainability 3.0 Exhibit in the Natalie & James Thompson Gallery at SJSU for the month of April 2011, and was a finalist in the EDF Sustainable Design Challenge in Paris in July 2011. This kind of exposure would not have been possible without the contributions of industrial design. Furthermore, the instructors from four of the five courses stated that their ZEM team outperformed the other teams in their class on their project deliverables, as shown in Table 7. The engineering ZEM teams, in particular, received top marks in their respective senior project courses for hardware, oral presentations, and final written reports.

Value to Instructor

Despite the added work required for this effort, some consistent benefits to the instructors in the form of professional development emerged from the faculty interviews.

Although some of the instructors were not happy with the lectures as they were delivered to the students, three of the five instructors remarked that the process used during summer meeting to develop the content involving feedback from the other instructors, was enjoyable and illuminating. Comments supporting this from the instructor interviews include the following:

> "And it was really [Instructor A] that said, here's why electricity is so popular to use from this entropy perspective. And I'm like wow, I mean that was great. She proved why electricity is used better than I could and so yeah, I consequently use her bit when I talk about it."

	Assignments	ZEM team grade*	Non-ZEM average team grade*
Mechanical engineering	Written report	95	87
	Oral presentation	99	87
	Hardware	100	95
Electrical engineering	Written report	90	89
	Oral presentation	96	89
Industrial design	Portfolio	NA**	NA**
Business	Written report	99	89
Public policy	Written report	93	82

*Grades scaled to 100 points, where necessary
**Although students work in teams in the industrial design course, they are graded individually on their portfolios; hence a team grade is not reported.

Table 7. Comparison of ZEM team grades to Non-ZEM team average grades in five participating courses.

"... the system that we used was quite good. Each of us did a draft lecture and then the questions, and we tried to see whether we could answer the questions based on another colleague's lecture. [. . .] in one case we couldn't quite understand what was being said and so actually that colleague [. . .] visualized it [. .] and did a really great job in trying to explain all that . . ."

"... when we did meet, I felt like it was very productive. It was just an exchange of ideas, a marketplace of ideas, just everything you think of at a university."

Furthermore, there have been multiple opportunities for the faculty to engage in scholarship directly from this work. There have been three conferences to date attended by a subset of the faculty team, where our work has been presented [30, 36, 37] a journal paper [30], as well as two other manuscripts currently in progress, including this one.

Finally, all five of the instructors indicated an advancement of their understanding of multidisciplinary collaboration and instruction, and/or a desire to continue in its engagement in some form. Representative remarks from the faculty instructors include the following:

"I think this was a great leap forward. I do, I think it was great. [. .] It takes a lot of courage to try to do something like that."

"I think that if this was something that became reality here at San Jose State I think sustainability is a valorous subject to really tackle, I really do think it is. But I think it has to be integrated at a much deeper level than it was contextually and disciplinarily . . .]

"And the thing is I just would say now I know – at least if we worked with the same majors I would know what their skill sets were and we would just say certain things up front."

"I would love to [co-instruct my entire course. . . .] I think it can be really beneficial to students, I think, and it's much more representative of the real world where they need to work together."

"I've never had to advise my students to work with personality issues and conflict so much [. . .] but I think it's an area where I [. . .] need to grow. [. . .]So, I'm not entirely discouraged by [this experience], because I think we did a lot of good, too, just as far as the project outcome was concerned

FUTURE WORK

A co-instructed senior project was not undertaken in the 2011-2012 academic year while the authors of this work undertook the analysis and assessment of the case study year. However, this model does not require any special administrative structure other than for interested instructors to find each other and to schedule overlap in their normal courses. It is fair to speculate that that the co-instruction model will be tested many more times in the upcoming future. Faculty members in the Communications department specializing in Dialog have expressed interest in developing modules on conflict resolution and project management, and they will be a key factor in future renditions.

Multidisciplinary instruction should ideally be introduced at multiple places in the undergraduate engineering curriculum, and not just during senior year. At SJSU, the formation of multidisciplinary team projects has also been incorporated into the freshman Introduction to Engineering course, required of all engineering majors. Student clubs and projects provide other opportunities for multidisciplinary interaction throughout the curriculum.

Interdisciplinary capstone experiences are also currently a hot topic in general education. Perhaps there will be a way for the co-instruction model to play a role in integrating general education and senior culminating experiences in a holistic way in the future.

CONCLUSIONS

A detailed case study of a co-instruction model of administering a multidisciplinary senior project was performed. This model is designed to replicate the cited educational benefits of team-taught, project-based learning and to incorporate modern skill sets into existing curricula, without introducing new courses or requiring a dedicated facility.

It typically takes years to implement multidisciplinary team-teaching effectively [26], and this model is no different. There were successes in the areas of project outcomes and benefits to the faculty, as well as documented areas requiring further work in future renditions. These findings may be useful to other universities embarking on the journey towards more integration and multidisciplinarity. Although every university differs in faculty mix and culture, there are concerns common to many institutions of higher learning and similarities due to the nature of academia.

The largely self-selected students working on the multidisciplinary senior project were more extroverted and open to new experiences than the students who chose to do a traditional senior project. The average GPA of the students on the multidisciplinary project was also higher. Out of the five participating classes, students in the political science class were the least interested in project-based instruction compared to traditional lecture. The differences between the multidisciplinary team students and the regular students should be considered in the application of the results here. It should also be an important consideration if the co-instruction model is scaled up to a requirement and no longer voluntary. The mix of personalities may be quite different under these circumstances. Differences in learning preferences from discipline to discipline must also be considered in designing multidisciplinary educational experiences in general.

The disciplinary lectures delivered in the fall semester proved to be of some value in imparting basic disciplinary concepts to a multidisciplinary student audience, and of limited value in at establishing an affinity identity among the multidisciplinary team and imparting an appreciation for disciplines outside of one's own. There were small but significant gains in the electrical engineering and business knowledge in the multidisciplinary group that were not predicted by students' GPA or pre-test scores. However, the average final score on the post-lecture quiz by the multidisciplinary team students corresponded to a percentage of 60%, indicating room for improvement in information retention. Student comments from a focus group indicated a perceived lack of difficulty and usefulness of the lecture content.

Students' satisfaction with the project experience was strongly and positively correlated to their rating of overall instruction quality and helpfulness. The project experience is paramount to the success of the co-instruction model, and to all courses with a significant amount of project-based learning in general. Co-instructing faculty should, at a minimum, be familiar with the literature on multidisciplinary instruction and project supervision, and have a strong track record of successfully supervising student projects. The conflict observed in the multidisciplinary project seemed to have contributed to some dissatisfaction with the project experience. Although conflict is a natural consequence of differing perspectives and can lead to more effective problem solutions, imparting more effective conflict resolution skills in the participants could overcome this roadblock in future renditions.

The subprojects in the overall multidisciplinary project outperformed the corresponding traditional disciplinary student projects in 4 out of the 5 participating courses. This provides evidence that features of the co-instruction model do foster high student achievement.

Lastly, benefits to the faculty instructors were found in this initial implementation of the co-instruction model. In general, faculty found the convergence of discipline on a topic of mutual interest to be interesting and illuminating. Furthermore, there have been multiple opportunities for scholarship and creative activities, which are typically rewarded in academia.

To conclude, an intrinsic benefit of the project was the merging of academic cultures. Students typically know little about the problems and values of students in other disciplines, which is a precursor to the lack of awareness in the real world. If the challenges uncovered here can be understood and overcome, the potential is great. Not only will students be able to tackle more ambitious and holistic projects, but the faculty will be able to effectively administer project-based learning to large groups of students without an inordinate number of different projects. If students can learn how to work effectively on multidisciplinary projects, they are more likely to be effective performers in the work place. Although there are many improvements that will undoubtedly be implemented in future renditions, the extent that the multidisciplinary project increased mutual awareness, for better or worse, is an accomplishment worth noting.

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REFERENCES

1. Sheppard, S.D., Pellegrino, J.W., & Olds, B.M. (2008). On becoming a 21st century engineer. Journal of Engineering Education, Special Issue, July 2008, 231–234.

2. Global Climate Change Education Project, NASA website, http://www.nasa.gov/offices/education/programs/descriptions/Global_Climate_Change_Education_Project.html

3. Environmental Education Grant, EPA website, http://www.epa.gov/enviroed/grants.html, retrieved Dec 2, 2010.

4. Climate Change Education: Climate Change Education Partnership Program – Phase I, NSF 10-542, NSF website, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503465, retrieved Dec 2, 2010

5. Science, Environment, Education and Sustainability, Cross-cutting program, National Science Foundation Website, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707, retrieved Oct 25, 2011

6. Morgenroth, E., Daigger, G.T., Ledin, A., & Keller, J. (2004). "International evaluation of current and future requirements for environmental engineering education." Water Science and Technology, 49(8), 11–18.

7. Heun, M., & VanderLeest, S. (2008, June). "Why a liberal and multidisciplinary education is needed to solve the energy crisis." Proceedings of the ASEE Annual Conference and Exposition. (17p), Pittsburg, PA.

8. National Science Board. (2007). Moving Forward to Improve Engineering Education. NSB-07-122. Arlington, VA: National Science Foundation.

9. ABET Inc. (2008). Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2009–2010 Accreditation Cycle. Retrieved January 29, 2009, from http://www.abet.org

10. Shields, M. & O'Connell, J.P. (1998, June). Collaborative teaching: reflections on a cross-disciplinary experience in engineering education. Proceedings of the ASEE Annual Conference. Seattle, WA.

11. Hirsch, P.L., Shwom, B.L., Yarnoff, C., Anderson, J.C., Kelso, D.M., Olson, G.B., & Colgate, J.E. (2001). Engineering design and communication: The case for interdisciplinary collaboration. International Journal of Engineering Education, 17(4–5), 342–348.

12. McKenna, A.F., Colgate, J.E., Carr, S.H., & Olson, G.B. (2008). IDEA: formalizing the foundation for an engineering design education. International Journal of Engineering Education, 22(3), 671–678.

13. Coles, E. (2001, June). Sustainable design in engineering and technology education: A multidisciplinary model. Proceedings of the ASEE Annual Conference and Exposition: Peppers, Papers, Pueblos and Professors. (pp. 9261–9265). Albuquerque, New Mexico.

14. Bachmann, C., Tang, J., Puffenbarger, C., & Kauffman, M. (2008, June). Engineering for non-engineering schools: A hands-on educational curriculum that addresses the need for renewable energy through undergraduate research and applied science. Proceedings of the ASEE Annual Conference and Exposition. (14p). Pittsburg, PA.

15. Costa S., & Scoble, M. (2006). An interdisciplinary approach to integrating sustainability into mining engineering education and research. Journal of Cleaner Production, 14, 366–373.

16. Miller, R.L., & Olds, B.M. (1994). A model curriculum for a capstone course in multidisciplinary engineering design. Journal of Engineering Education, 84(4), 1–6.

17. Van Kasteren, J.M.N. (1996). Interdisciplinary teaching with engineering education. European Journal of Engineering Education, 21(4), 387–392.

18. Jansson, P.M., Riddell, W., Vizzi, N., Bhatia, K., & McDevitt, R. (2007, June). Engineering students transforming public policy to promote green power. American Society for Engineering Education Conference. (9p). Honolulu, HI.

19. Skates, G.W. (2003). Interdisciplinary project working in engineering education. European Journal of Engineering Education, 28(2), 187–201.

20. Daems, W., De Smedt, B., Vanassche, P., & Gielen, G. (2003). PeopleMover: An example of interdisciplinary project-based education in electrical engineering. IEEE: Transactions on Education, 46(1), 157–167.

21. Cheville, A., (2010) "Transformative Experiences: Scaffolding Design Learning Through the Vygotsky Cycle," International Journal of Engineering Education 24(4), 760–770

22. McNair, L.D., Newswander, C., Boden, D., and Borrego, M. (2011). "Faculty and Student Interdisciplinary Identities in Self-Managed Teams," J. of Engineering Education, 100(2).

23. Borrego, M., Newswander, L., McNair, L.D., McGinnis, S., and Paretti, M., (2009). "Using Concept Maps to Assess Interdisciplinary Integration of Green Enginnering Knowledge," Advances in Engineering Education, 2(1), pp. 1–26

24. Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D., & Leifer, L.J. (2005). Engineering design thinking, teaching, and learning. Journal of Engineering Education, Special Issue, January 2005, 103–120.

25. Bass, R.B. (2006, October). A bachelors degree program in renewable energy engineering. Proceedings of the 36th ASEE/IEEE Frontiers in Education Conference, (pp.13–16). San Diego, CA.

26. Ochs, J.B., Watkins, T.W., & Snyder, D. (2003, June). Staying in tune with engineering education. Proceedings of the ASEE Annual Conference and Exposition. (pp. 7823–7833). Nashville, TN.

27. Jeffrey, Paul, (2003) "Smoothing the Waters: Observations on the Process of Cross-disciplinary Research," Social Studies of Science, 33(4), 539–562

28. Aagaard-Hansen, J., (2007) "The Challenges of Cross-disciplinary Research," Social Epistomology 21(4), 425–438

29. Borrego, M. & Newswander, L.K. (2008) Characteristics of successful cross-disciplinary engineering education collaborations. J. of Eng. Education, 97(2) 123–134

30. Rhee, J., Parent, D., and Oyamot, C., (2012) "Influence of personality on a multidisciplinary senior project combining innovation and entrepreneurship," Int. J. of Eng. Ed., 28(2). Also published in proceedings of 2011 Mudd Design Workshop VIII: Innovation and Entrepreneurship, Claremont, CA, May 2011

31. S. D. Gosling, P. J. Rentfrow, and W. B. Swann, "A very brief measure of the Big-Five personality domains* 1," Journal of Research in personality, 37, 2003, pp. 504–528.

32. D. J. Ozer and V. Benet-Martinez, "Personality and the prediction of consequential outcomes," Annu. Rev. Psychol., 57, pp. 401–421, 2006.

33. Rhee, J., Cordero, E.C., and Quill, L.R., (2010) "Pilot Implementation of an Interdisciplinary Course on Climate Solutions," International J. of Eng. Ed., Vol. 26, No. 2. pp. 391–400. Also published in proceedings of 2009 Mudd Design Workshop VII: Sustaining Sustainable Design, Claremont, CA, May 28–30, 2009

34. "SJSU ZEM Team – Getting to Work," http://www.350.org/en/node/23300, retrieved 4/11/11

35. "Battling Climate Change, Locally," San Jose Mercury News, October, 11, 2010

36. NSF Engineering Education Awardees Conference, Arlington, VA, March 4–6, 2012 and Reston, VA, Jan 31-Feb 2, 2010

37. Open 2012: NCIIA's 16th Annual Conference, San Francisco, CA, Mar 22–24, 2012 and Open 2010: NCIIA's 14th Annual Conference, San Francisco, CA, Mar 25–27, 2010

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APPENDIX A: LIST OF ALL STUDENT PROJECTS IN CO-INSTRUCTION SEMESTER (FALL 2010)

Electrical Engineering: ZEM House EE team; Formula Hybrid car; Programmable gate arrays for audio signal processing; bird call identifying game system; Lifting system for handicapped; Power meter for wind turbine; Optical memory system

Mechanical Engineering: ZEM House ME team; Solar water distiller; Solar oven; Thermally stratified store for solar hot water heating; ASHRAE HVAC competition design team; Shifter kart lifter

Industrial Design: ZEM House ID team; ID-specific ZEM House II; ID-specific ZEM House III

Green Entrepreneurship: ZEM House BUS team; Purified water in California; Artful trashcans; Mobile green recording studio; Green snapback hats

Public Policy: ZEM House PP team; additional team topics no longer available.

APPENDIX B. KEY TOPICS IN DISCIPLINARY LECTURES

Electrical Engineering: Electricity, power, power consumption; transfer functions; analog vs. digital; feedback; Ohm's law; smart grid, photovoltaics, data transmission

Mechanical Engineering: Subdisciplines of mechanical engineering; climate and energy; energy vs. power; conservation of energy; transportation, building heating/cooling, renewable energy sources

Industrial Design: Energy consumption worldwide; stakeholders in design; behavior and consumption; ecodesign strategies; product lifecycle; cradle-to-cradle footprints

Green Entrepreneurship: Energy as a commodity; price of renewable/conventional power; economic supply and demand; influence of policy; growth of renewable energy; feasibility and cost benefit analysis; payback period; net present value;

Public Policy: Role of public policy in society; energy; taxation; health; global warming

APPENDIX C. ADDITIONAL GUIDELINES FOR ZEM STUDENTS IN FALL 2010 IN RESPONSE TO FORMATIVE ASSESSMENT.

San José State University
Additional Guidelines for ZEM House Project
ME195A/B, EE198A/B, Bus186S, DSID125/128, POLS130
Fall 2010

Here are some additional guidelines for use on the multidisciplinary ZEM house project, moving forward. These are suggestions only (albeit very strong suggestions!).

Team Liaisons and Project Management

The 5 instructors for the pilot ZEM house project strongly suggest that each disciplinary team identify a team liaison. This person will be responsible for communication between their disciplinary team and the 25-student multidisciplinary team. Furthermore, the liaisons should meet for at least an hour once a week at a mutually agreed upon time, to discuss progress and needs of their team and the project as a whole.

Each team should identify this person ASAP and post this information on the D2L discussion board. Furthermore, the liaison should ensure that his/her availability is indicated on the group Doodle site, and make efforts to nail down a common meeting time with the other liaisons.

At the first liaison meeting, one or two project managers should be identified. Duties of the project manager(s) (in addition to their liaison duties) include keeping track of the project schedule and budget, as well as taking meeting minutes and posting them on D2L. This information should also be posted on D2L ASAP.

Minimum Posting Requirements

A critical mass needs to be achieved for communication on the online discussion board to be useful. Hence, we would like to strongly suggest that **each student** be **required to post at least 3 comments per week**. The more comments there are, the more you will check it, and the more useful it will become. In some cases, your faculty instructor might require it through a participation or teamwork grade component. Please check with your instructor to see if this is the case.

We know that some of the subgroups have their own networks (e.g. Google groups, Dropbox, etc. . .). That is fine for the nitty gritty details that the rest of the project need not be concerned with, but the bulk of the documentation, information, and communication needs to move to the D2L site for the entire project team to see. Please make an effort to do so.

When posting to the discussion board, please make an effort to see if the topic has been introduced and discussed previously before starting a new thread. When expecting an answer to a post, please also make an effort to see if the question has been answered elsewhere. Lastly, please make sure that your comments are representative of the subject under which it is posted. If you go off on a tangent or change the subject, you should start a new thread. The organization of the discussion board will largely hinge upon our efforts in this area.

Open and Respectful Exchange of Ideas

Comments made in-person or on the discussion board in an insensitive, disrespectful, or confrontational manner is not acceptable, whether deliberate or accidental. That being said, we absolutely do want to encourage the free generation of ideas, without fear of ridicule or dismissal. Please keep in mind that the other students on the project will have different opinions and backgrounds, and will in most cases have had a different course of study than yourself. Part of the challenge of this project is to find ways to involve all stakeholders in active and productive debate, consider ideas you might not have thought significant previously, and to converge on joint decisions. This will involve active effort on everyone's part to explain their contributions and opinions and to understand those of the rest of the team. If you need to use overly technical terms or uncommon acronyms, it would be appropriate to do any of the following: define them beforehand, provide a layman's translation, and/or post it under an appropriately technical heading to encourage readership by the appropriate audience.

An example of respectful/sensitive language will be presented with a hypothetical situation. Let's say that someone suggests that the ZEM House should accommodate left-handed users and you disagree. The following response (or responses like this) is less than ideal:

> "Left-handed people make up less than 10% of the population, and thus are not worth considering."

> Any of the following would be better, and would leave the door open to further debate:

> "It is a good goal, but I think the designing the house for the right-handed majority is going to be a lot of work for a senior project already. Maybe we can address this in the future work for this project."

> "If we research the requirements for the left-handed, we can evaluate whether it should be one of the specifications for the house."

> "I feel that we have other priorities on this project, but I am open to feedback."

Of course, anyone should be free to chime in at this point with an opinion.

Diversity and Unlawful Discrimination

Lastly, just for the sake of awareness, there are several categories of remarks pertaining to diversity that are intended to protect against unlawful discrimination as defined by state and federal laws. You may not discriminate or harass anyone on basis of the following:

- Age
- Disability or medical condition

- Hostile environment
- Race, color or national origin
- Retaliation
- Sex, gender or gender identity
- Sexual orientation
- Veteran status

Please be sensitive to our diverse populations and their needs when communicating arguments, rationales, and decisions.