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Sustaining Sustainable Design through 'Normalized Sustainability' in a First-Year Engineering Course

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In the fall of 2007, Purdue University began integrating sustainable design topics into our Introduction to Engineering Problem Solving and Computer Tools course which our first-year engineering students complete prior to advancing to their specific engineering disciplinary programs. In the Spring of 2008 we began assigning a six-week design project related to Sustainable Design. The students work in teams of three-to-four students to consider their living spaces and how they might make those spaces more sustainable. In this paper, we present an overview of the educational activities, including the material that is presented to students and more details on the design project. Additionally, we present an analysis of some of the students' final projects. We present three cases which represent different student responses. This work will contribute to what we as a design education community understand about first-year engineering students' ability to engage with this material.

Keywords: sustainability; design; first-year engineering; students; design projects; normalized sustainability

1. SUSTAINABILITY

1.1 'Normalized sustainability'

As a broadly defined concept, sustainability has its roots in the UN's 'Brundtland Commission report' [1], which put forward as 'sustainable development' the actions that provide for current human needs and standard of living without compromising the ability of future citizens to meet their needs. In practical and engineering terms, this is often seen through an environmental lens; sustainable engineering requires the implementation of strategies that explicitly recognize non-infinite resource availability, environmental and ecological system disruption, population growth pressures, eco- and human toxicity, protection of biodiversity, energy renewability, and limits of natural systems to incorporate pollution without long-term negative impacts. But full sustainable design is larger, and needs to include the interdisciplinary aspects of social equity and long-term economic viability along with environmental issues; these three metrics comprise the 'triple bottom line' of sustainability. In academic curricula, sustainable science and engineering as a discipline is similarly broad, and challenges engineers to integrate industrial, social, and environmental processes [2] into coherent and comprehensive design solutions, and to approach sustainability as a 'frame of mind' [3].

Sustainability is long-term and systems-wide in its outlook, and the way that engineered objects, processes, and systems are designed can have a long-ranging impact on future needs of natural and social resources, and environmental services. As students learn the design process, it becomes critical that they understand the long-term implications of their design choices. Sustainability becomes an important part of a complete engineering design education for the next century, therefore, for several reasons:

- The questions of scale ('long-term' and 'systems-wide') matter: the classical metrics of good design (applicability, efficiency, cost, creativity, scalability, flexibility) are still the same in a sustainable engineering mindset, but the scale is different. Students need to be taught to ask explicit questions about how these metrics hold up long into the future, and in a global system where the impacts on everyone and everything (not just the immediate client or customer) are considered.
- The current engineering student will do his or her professional work in a world of shrinking resources and changing environmental concerns; he or she will be required to work within these constraints and understand the impacts of engineering actions on them.

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- Engineering sustainability ideas stress and hone the desired student skills of creative problem-solving, interdisciplinary thinking, and complexity of analysis.
- There is a significant ethical responsibility inherent in sustainable engineering practices; ethical engineering education requires consideration of the impact of a design to others and the broader societal impact of the engineering enterprise.

Considering these characteristics, it is clear that sustainability is, in fact, a prerequisite for *all* good engineering design; it is not a fad concept, but is instead an expression of core values of long-term engineering that recognizes the increasing realization that the long-term and large-scale will be forgotten if not explicitly included in the design process.

We have termed this conception 'normalized sustainability,' where we convey to students the viewpoint of sustainability as a normal part of the essence of engineering and a standard part of the design process, and not an added-on, uni-disciplinary, or 'special interest' concern. This framing of sustainability may be particularly important for first-year students, who may not yet have a clear conception of the boundaries of engineering and engineering disciplines, and who may therefore be able to more easily incorporate sustainability into their personal definitions of what engineers do.

Other authors have likewise argued that sustainability should be recognized as a 'critical literacy' [4], and an integral part of engineering practice, and thus argue that sustainability should be incorporated throughout the engineering curriculum [4–6]. Davidson et al. [7] also include 'consider sustainability in all engineering decisions' as one of several challenges that should be considered when incorporating sustainability into engineering curricula.

Over the past decade, American engineering disciplinary societies have recognized the importance of sustainability and released relevant policy statements. In 1999, the American Society for Engineering Education (ASEE) Board of Directors recognized this need and declared, in an official statement, 'ASEE believes that engineering graduates must be prepared by their education to use sustainable engineering techniques in the practice of their profession' [8]. Engineering professional disciplinary societies, including the American Society of Civil Engineers (ASCE), the American Society of Mechanical Engineers (ASME), the American Institute of Chemical Engineers (AIChE), and the National Society of Profesional Engineers (NSPE), have responded by including sustainability as part of Engineers' Codes of Ethics or similar documents [9–12]. For academic institutions, ABET, formerly the Accredition Board of Engineering and Technology, includes sustainability issues in at least two of the general student outcome criteria: 3(c) explicitly cites 'sustainability' as a design constraint that students should be able to address, and 3(h) stresses the importance of a broad education that situates engineering solutions in societal context, an important aspect of sustainable engineering [13]. The placement of sustainability within Codes of Ethics moves the responsibility for sustainability beyond the level of the project or the level of the team to the level of the individual engineer—ethical responsibilities, by definition, must be met by *every* engineer during *every* professional action. To prepare all students to meet their ethical responsibilities, therefore, sustainability should be normalized throughout engineering training.

At the same time, new organizations and initiatives have sought to establish sustainability as a hallmark of higher education in general. Viewpoint articles in top journals such as *Science* have called for the broader incorporation of sustainability as a fundamental part of all education [14, 15]. The Association for the Advancement of Sustainability in Higher Education (AASHE), launched in 2006 and now numbering about 650 member universities worldwide, advocates sustainable practices on both the operations and academic sides of the university. This presents an interesting opportunity for engineering educators to use their campuses as a 'living laboratory' to exhibit and design sustainable practices.

Recent literature includes examples of incorporation of sustainability concepts into curricula of particular engineering disciplines or courses: for example, the development of principles of 'green chemistry' [16] or 'green engineering' [17] within Chemical Engineering curricula and courses; the development of 'industrial ecology' concepts [18]; 'green design' and pollution prevention [19]; or materials engineering sustainability [20]. Some efforts have catalogued courses and programs related to engineering or environmental sustainability (e.g., [21]; and the Center for Sustainable Engineering's Benchmarking Report [22]). Additionally, conferences have begun to introduce special sessions and workshops on sustainability in engineering: for example, the 2008 FIE (Frontiers in Education) conference, sponsored by ASEE and IEEE, held a special session on sustainability in engineering education [23].

But these efforts still express sustainable engineering as a distinct skill that only some engineers will learn; many courses included in the CSE's Benchmarking Report [22] are specialty or elective courses, not core curricular requirements (some exceptions include the first-year engineering courses described by Goff and colleagues [24] and Thompson [25]). By focusing the first-year students' design project around an issue related to sustainability, we provide the students with an opportunity to consider sustainability as a key criterion in engineering design. While the explicit focus of the projects was on the sustainable redesign of their living spaces, students were also expected to integrate precepts of sustainable design into their problem solutions.

1.2 Sustainability and first-year engineering students

In this paper, we present two complementary aspects of our educational intervention: a description of the work that we have accomplished to date in preparing educational activities for first-year engineering students, and research activities aimed at understanding the students' abilities to apply sustainability in engineering design, and some critical reflection on our accomplishments. The educational activities aim to couple sustainability with engineering design so that students might understand sustainability as an integral part of engineering design. The research activities aim to examine how students are able to consider sustainability while also engaging in design activities such as identifying relevant criteria and constraints, gathering appropriate information, modeling implementation costs, considering the feasibility and implications of their solutions and appropriately communicating design solutions. Additionally, the research activities examine the types of solutions the students considered.

There is often a disconnect between research and practice activities—too often practitioners do not incorporate research findings to improve their practice and too often research is conducted in a way that no longer reflects authentic practice. This project attempts to bridge that divide. Our challenge in doing so was to ensure that the research was rigorous while also ensuring that we were providing our students with a sound educational experience. Additionally, the implementation of any pedagogical innovation to more than 1600 first-year students at once is often fraught with technical difficulties. To balance the rigors of research methods with the practicalities of teaching our first-year students their first engineering course, we have chosen to follow the tradition of what some have called a 'scholarship of teaching and learning' [26] or what others call 'educational practitioner inquiry;' Connolly and colleagues [27] argue that the critical characteristics of this form of inquiry include (p. 22):

- 'Drawing upon the work of others, including disciplinary colleagues, education researchers, and students;
- Posing an explicit question about the effectiveness of one's practice;
- Creating and following an explicit design or plan;
- Collecting credible evidence to answer the question;
- Analyzing and interpreting evidence;
- Reflecting on one's findings;
- Acting on one's findings;
- Engaging in ongoing and cyclical inquiry;
- Documenting and disseminating processes and outcomes of inquiry; and
- Being principally responsible for conducting the inquiry on one's own practice.'

The production of this paper situates us in the midst of the 'reflecting on one's findings' state, as part of the broader 'cyclical inquiry.'

2. EDUCATIONAL ACTIVITIES

After pilot testing of course materials related to sustainable design in Spring 2008, we introduced the topic on a larger scale in Fall 2008; approximately 1200 first-year engineering students participated. Students were first exposed to sustainability in engineering through a section in the course notes packet and a one-hour lecture, and then, over several weeks, the students completed a major design experience related to sustainability. The students' knowledge and abilities were assessed through three means: homework assignments, exam questions, and their design project (which is described in more detail in section 2.2).

2.1 Student introduction to sustainability concepts

The course notes introduced sustainable concepts and made the case for normalized sustainability throughout all engineering, casting sustainability as long-term, broad-scale planning and consideration of impacts. The course notes further put forward the interconnectedness of systems and encouraged students to consider global impacts; about design, the notes said, 'design requires consideration of where materials come from, where they will continue to come from, how much waste will be produced and what will happen to it, how much energy is needed and in what forms, what long-term maintenance costs will be, what the lifetime expectations are, what public health implications there are, and what neighboring systems will be affected and how . . . These are the considerations of sustainability, and design without these considerations is, simply, bad design.' [28]. To assist students in applying the philosophy of sustainability to their design project in the course (and in future courses), they were given definitions and descriptions of five aspects of sustainability and how they relate to engineering:

(1) Natural resources and energy; with descriptions of the current state of resource availability.
(2) Waste disposal, repurposing, and recycling; with issues of the waste stream.
(3) Public health; integrating the traditional safety responsibilities of engineers to material toxicity and public health.
(4) Upfront vs. long-term costs; which encouraged a broader and more complete definition of the cost constraints of design.
(5) The 'triple bottom line' [29]; introducing students to the use of design criteria on the three scales of economic, social, and environmental terms.

Finally, the course notes introduced three tools that 'may be helpful as you consider sustainability in designs, including in the *design project* for this course' [28; emphasis added]: (1) footprint analysis, (2) systems design and the idea of embedded energy, and (3) life-cycle analysis and cradle-to-cradle design. A one-hour lecture with active learning reinforced these concepts and allowed for time for student engagement and questions, concentrating on these three tools. After reviewing announcements, the learning objectives were presented: (1) understand why sustainable designs are part of good engineering, (2) define the ideas of cradle-to-cradle; energy footprint; systems design, (3) estimate a way to calculate your own energy footprint and (4) discuss these concepts' applicability to your design project.' Then the instructor prompted the students to brainstorm resources. Following a discussion of reasons for considering sustainability, students discussed in small groups how sustainability might effect public health. After this, the instructor discussed the 'triple bottom line', the metaphor of the footprint (with an exercise for students to consider their own energy footprint), cradle-to-cradle design and systems design before introducing the design project and giving students time to discuss the project with their teammates. The ability of students to apply these concepts immediately to their design project increased the success of this lecture over similar efforts in a previous year. Earlier in the semester the lecture periods included material on a model of engineering design as well as user-centered design. The class period one week after the lecture on sustainability introduced the practices of defining goals, criteria and constraints and the students were able to practice these processes by defining goals, criteria and constraints for their sustainable-design project. Additionally, one class session was devoted to needfinding activities.

2.2 The design project

For their design project, teams of three-to-four students were asked to consider ways in which they might make their own living space more sustainable and then to draft a memo to an appropriate stakeholder (of the students' choosing; examples include the university President, the residence hall manager, and student peers). Students endeavored to make a compelling argument so that the stakeholder would adopt the proposed changes. The project consisted of six pieces, the initial project description and five milestones for the students to complete: generating project design ideas (M1), defining the client, goals, criteria, and constraints (M2), drafting a memo communicating the design (M3), reviewing peers' memos with TA guidance (M4), and writing the final memo (M5). Students completed M4 during a lab, allowing them time to work on their project with access to their TA and Professor for feedback and other help while becoming familiar with the rubric that was used to evaluate the final memo (Appendix A). The rubric designed to assess the effectiveness of the memo was used for peer review and final grading by TAs, and was based on a 3-point scale (2 pts = addressed well, 1 pt = considered, but not addressed well, 0 = not addressed adequately) on each of the following topics:

- Message: The explicit message about sustainability is desirable and clearly articulated.
- Message: Implicit messages are desirable for the client.
- Technical content: Goals and constraints.
- Technical design: Evidence.
- Memo: Connection to the client.
- Memo: Connection to society.
- Memo design: The memo stands alone without verbal explanation.
- Memo design: The viewer understands the flow of information.

The result of this rubric was that 8 pts were designated to the memo communication, and 8 to the design itself.

3. RESEARCH APPROACH

The educational activities described in the previous section both serve as an example of one attempt to integrate sustainability into students' understanding of design, but also serve as the context for conducting research on students' ability to engage in sustainability-centered design projects. Therefore, we focus on the students' design projects rather than the other measures of students' sustainability knowledge (i.e. the homework assignments and exam questions described in the beginning of section 2). For the purposes of this study, we select three cases of student work (final memos outlining the student teams' proposals): an exemplar team, a team that wrote a less-sophisticated memo, and one case that illustrates some of the challenges that some students encountered with the project.

The lack of prior research on how students engage with sustainability curriculum in general as well as more specifically how students engage with sustainability *design* resulted in fundamental research questions:

- *What concepts of sustainability do first-year engineering students incorporate into design projects?* This question must be considered in the context of the preparation we provided—the definitions and the tools described in section of this paper describing the instruction students received. Students accessed these various definitions and tools to a greater or lesser extent.
- *How well are students able to address a sustainability-related design problem?* We expected students to respond differently to each of the messages related to sustainability. Particularly, we presumed that the consideration of second-order effects would be challenging for students because they are by nature more abstract. Since we expected that students would not be capable of succeeding at this, we did not include this among our learning objectives. From an exploratory perspective, however, it is useful to know how many students introduced second-order arguments in their discussion.

- *What responses or questions did our intervention elicit?* While students tend to be passionate about sustainability in the abstract, the project was expected to bring to light misconceptions, incorrect assumptions, and simply poor research practices. For our purpose of normalizing sustainability, the questions that this instruction generates are as important as the questions it answers. By participating in the class, the discussion has just begun.

To select the cases that we present in this paper, we analyzed a subset of the students' final deliverables, the memos. We used a random number generator to select 58 of the 262 memos that were submitted. The sample of 58 includes memos from across the 10 sections (and 5 instructors) of the course. Two of the authors each reviewed 34 of 58 memos; 10 memos were reviewed by both authors while the remaining 48 (24 per author) were reviewed independently. The memos were randomly assigned to the two reviewer-authors so that for any section there was an equal chance that one or the other author was reviewing a memo from that section.

Initially, each reviewer-author read through several memos for the purposes of gaining an overall sense of the dataset in relation to our three research questions. From this initial process of reviewing the memos, we generated the following set of criteria by which we then assessed each of the 58 memos in order to identify cases of exemplary team proposals and less sophisticated proposals:

(1) Did the team include at least one citation for each major idea that they presented?
(2) Did the team include citations beyond just corporate literature (i.e., only information from the companies selling the products)?
(3) Did the team account for the costs associated with implementing each major idea within their proposal?
(4) Did the team look for second-order effects (i.e. the possible side-effects) associated with their proposal?
(5) Did the team use more than an economic argument to advocate for their proposal?

Each of these five criteria were evaluated dichotomously: either the team did (yes) or did not (no) address the criterion. This set of criteria differ from the rubric used by the TAs because we were engaged in a 'theory-generation' stage of data analysis: we did not have any prior expectations on what our students would learn from this experience. These criteria came out of the data themselves to help us distinguish what we considered to be adequate or insufficient products. This data analysis allowed us to calibrate our expectations of the students for subsequent iterations of the intervention.

Even with the understanding that this new rubric evolved to conduct research that is theory generating, some may be concerned that the mismatch of the research rubric and the rubric released to students belies a concomitant mismatch between our learning and how students were assessed. To ensure the connection of learning objectives and assessments, student project grades were tied to the original rubric. Further, other assessments measured the course learning objectives:

- feedback gathered during class assessed the ability of students to engage with sustainability on both a personal level and in the context of their future careers;
- sustainability-related questions included in the course exam; and
- sustainability-related homework assignments.

Finally, the research presented in this paper is informing future versions of the rubric.

In addition to evaluating the 58 memos according to the five criteria above, we also coded the memos using an emergent coding scheme for recommendations (e.g. solar panels, insulated windows, new appliances). In the next section, we present the results from our evaluation of the 58 memos across the five criteria as well as for recommendations.

4. FINDINGS

In this section, we first present results from the analysis of the 58 memos that we conducted to select cases. Following these results, we present three cases: an exemplar team, a team that displayed a less-sophisticated approach to the project, and a team that encountered a challenge in their project.

4.1 Results from the content analysis

While a small number of memos discussed only one solution, it was more common for the memos to recommend the implementation of multiple solutions (e.g. installing solar panels *and* installing double-paned windows). The solutions that the students recommended included: replacing incandescent light bulbs with CFLs (15), replacing incandescent light bulbs with LEDs (7); installing automatic sensors for lights (7) and faucets (6); installing low-flow showerheads (9), faucets (5) and toilets (7); making changes to the heating and air conditioning system (7); replacing appliances with energy-efficient appliances (6); encouraging students to action through contests (4) and seminars (1), providing more opportunities for recycling (7); installing double-paned windows (8); installing solar panels (7); and installing geothermal heating systems (3). Less common solutions included: installing awnings over windows, removing walls in the dorm rooms so that four students share a microwave, TV and refrigerator instead of only two students, using eco-friendly cleaning supplies and rain-harvesting.

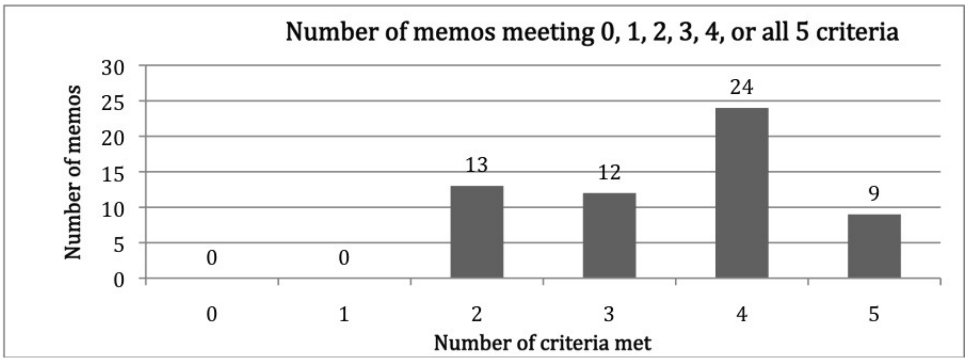

Fig. 1. Number of memos meeting a given number of criteria.

The majority of the memos did not meet all five of the criteria that we used to differentiate 'exemplar' memos from 'less sophisticated' memos for the purpose of selecting cases (Fig. 1). However, of the memos that did not meet all five criteria, nearly half (24 of 49) did meet four of the five criteria (Fig. 1).

The two criteria that were most frequently unmet (Table 1) were including information about the cost of implementing the proposed ideas and including consideration of second-order effects (possible side-effects) of implementing proposed ideas.

Half of the memos that we analyzed did not include complete cost information. In some cases, the memo did not include any acknowledgement that there would be costs involved with implementing their solutions; in other cases, the memo included rough estimates or ungrounded cost estimates, while in yet other cases the memos included cost information for part of their solution, but not for the remainder of the solution. This suggests that half of the teams included in the study did not fully engage in mathematical modeling activities while thinking about sustainability: they did not link sustainability with this engineering design activity.

Slightly more than half of the memos did not consider 'second-order effects'—for example, considering the possible negative environmental aspect associated with used light bulbs when suggesting that CFLs replace traditional bulbs. We might consider that discussion of these side-effects and/or implications of the design solutions could be one expression of considering the feasibility of the design solution(s).

A final aspect of engineering design that we can consider is the ability to gather appropriate information related to possible design solutions. Two of the remaining three dimensions—including citations for each major idea and including citations from sources other than the companies making the products—provide us with the insights that, in most cases, the students were able to effectively find credible information related to the design solutions that they considered.

4.2 Case 1: Exemplar

Team 1 chose to focus their recommendation on a single approach: replacing single-pane windows in one residence hall with double-pane windows. By focusing on a single recommendation, the team was able to discuss many dimensions of the recommendations in their memo. They began their memo with a short overview of their proposal—increasing sustainability 'by replacing the current windows with new windows to decrease the energy required to cool and heat the apartments'—and the identification of their design goal—'Our goal is to reduce the cost of the energy required to heat and cool all the apartments in Purdue Village by $90,000 a year, or about 10% of the overall cost.'

In the following paragraphs, the team provided a rationale for why they chose a particular residence hall, the drawbacks of single-pane windows, the 'R-value (the measure of thermal resistance, where higher is better)' associated with single-pane windows and with double-pane windows, information about the cost of the windows themselves, information about the costs that would be associated with installing the windows ('labor . . . sometimes can be just as expensive as the cost of the materials'), calculations for the total number of windows that would be needed, a total of six references, a rationale for how new windows would not only save money but increase people's enjoyment of their living space and an approximation of the total amount of energy and money that would be saved:

Table 1. Numbers of memos meeting each of the five criteria used for selecting cases

	1. External citations	**2. Citations for each point**	**3. Included cost**	**4. 2nd order effects**	**5. More than cost**
Met the criterion	46	45	29	30	54
Did not meet the criterion	12	13	29	28	4
Only criterion not met	*4*	*2*	*9*	*9*	*0*

> According to Energy Star, a 2,000 square foot home with 300 square feet of windows (a 15% window to floor space ratio) in the city of Indianapolis can save $345 dollars a year if upgrading from single-pane to energy-star rated double-pane[5]. A typical apartment has 515 square feet of flooring and 80 square feet of windows (a 15.55% ratio). Thus, we assume that the loss of energy is proportional, and an apartment will lose about 3.75 times less energy than the typical house Energy Star's calculations are based upon.

> We were charged to come up with an idea to make the School residencies more sustainable. We have chosen to increase the sustainability of the Purdue Village apartments by replacing the current windows with new windows to decrease the energy required to cool and heat the apartments. Our goal is to reduce the cost of the energy required to heat and cool all the apartments in School Village by $90,000 a year, or about 10% of the overall cost.

The team's solution also involved an innovation suggestion—incorporating [Building] Construction Management students in the construction work:

> Also, some majors require that a student attains a certain number of hours of construction work, and this could easily count towards those hours. For example, students in the Business Construction Management are required to log 800 hours of hands-on construction before they can graduate[4].

Including the students in the work could lower the cost of implementation, and would also provide the Building Construction Management students opportunities to learn and 'log hours' while working on campus. In contrast, many teams did not consider the construction cost associated with replacing single-pane with double-pane windows, let along creative ways of minimizing those costs. This consideration of the cost of construction and ways to minimize this cost is related to the idea of 'second-order effects'; however, the team addressed this criteria even more explicitly when they considered the impact of the construction on the students who would be living in the residence hall: 'Of course, to minimize the tenant's discomfort, construction would only take place in the summer months, or when the tenants allow it.'

4.3 Case 2: Less sophisticated

Team 2 included several recommendations in their memo: adding insulating film to windows (essentially creating a second pane), installing alarms on doors that would sound if the door is left open too long (letting out too much warm/cold air), replacing the current light bulbs with LEDs, eliminating unnecessary lights (e.g. lights that solely served a decorative purpose), placing 'a master power switch in each dorm room that controls the entire room's electricity,' making changes to the dorm room heating system and 'keeping the stairwells at a moderate temperature.'

In addition to not explicitly identifying the key criteria and constraints that they considered, Team 2 also did not explicitly identify the goal that they were addressing. Neither did Team 2 provide relevant references for each of the ideas that they suggested, but they did gather information from sources aside from company websites. Also, Team 2 did not provide any information about the costs associated with implementing their ideas, although they did engage in mathematical modeling associated with calculating the amount of energy that could be saved with each approach. Finally, Team 2 did not provide insights into possible 'second-order effects' associated with their recommendations; they might have considered addressing the aesthetic implications of installing plastic wrap insulation to the windows, the process of installing new LEDs and disposing of old light bulbs, or the possible negative implications of keeping hallways and stairs at a moderate temperature (which may be much cooler or warmer than dorm rooms) temperature.

The team considered some interesting possibilities for making their living space more sustainable, such as the master power switch that would allow a student to turn off all of the power in their dorm room:

> The idea is that this would enable students to turn off everything electric in their room when they leave for an extended break or vacation. This would turn off all nonessential electronics so that energy is not wasted when there is no one even in the room.

and the alarms that would sound if a door was left open too long:

> In an effort to let students know when they have held the door open too long, a warning alarm that sounds when a door is held open for too long would prevent students/residents from holding the door open for extended periods of time.

However, the team did not discuss each of their ideas in enough detail to demonstrate that they had engaged in design activities such as gathering information, modeling and feasibility analysis.

4.4 Case 3: Challenge

A third case that we present is a case where students thoroughly researched an approach that they believed would benefit the university (in terms of cost and sustainability), but in the end was a very costly approach. The team approached a course instructor about their dilemma, as the final project deliverable was due shortly after they realized that their approach would be very costly. The course instructor advised the students to reframe their memo as a report on what the residence halls should *not* do to increase sustainability. While Team 3 decided that they would incorporate this 'what not to do' advice in their memo, they included it as one of many sections:

> Another idea that came up would be to install solar panels on the roof of the building of Ford. Through research on the internet, it was calculated that a building the size of Ford Dining Court would require approximately $25 million of initial costs for solar panels. However, after researching this idea, we found out that solar panels would be a bad idea for Purdue

> to invest in because the lifespan of a solar panel is only 20–25 years where as the time to break-even would take 35 years. We could also change every single light bulb to energy saver bulbs. These light bulbs will be able to last three times longer than the average light bulb also being 300% more efficient.

In addition to this advice, the team suggested that the residence hall eliminate the use of dining trays (used to carry plates, bowls, cups, etc.): 'trays both directly and indirectly promote excess wasting of water, food, and chemicals.' Alternatively, the residence hall might eliminate the use of plates and 'instead have dividers in the trays.' Both approaches would reduce the number of dishes (trays or plates) that would need to be washed. The students also suggested investing in biofuels.

Overall, despite a change in their project direction at the end of the semester, the students were still able to write a memo that met four of the five criteria. The only criterion that the team did not address was considering the cost of implementation—while the team clearly considered the cost-prohibitive nature of installing solar panels, they did not discuss costs associated with their other suggestions.

5. NEXT ITERATION OF THE PROJECT (SPRING 2009)

Based on our experiences in the Fall 2007 and Fall 2008 semesters, we recognized that students needed a better connection with the sustainability content, and that we could improve the connections between the lecture content and other aspects of the course, further integrating sustainability into the first-year engineering curriculum. As a result, we rearranged the schedule and embedded content into multiple assessment frameworks.

Therefore for Spring 2009, we discussed sustainability via a mini lecture in lab in Week 5 of the semester. The teaching assistants conducted the mini lecture in each section, and the content remained similar to that first drafted in Fall 2007. However, we brought sustainability contexts into two story problems: one focused on CAFE standards where the main purpose was to have students practice calculating descriptive statistics using MATLAB and Excel; the other focused on calculating the pay-back time of a higher efficiency HVAC system, using linear regression to predict future energy costs. In addition, we incorporated the sustainability content into basic short answer questions on a lab quiz and on both the first and second course exams.

Most prominently, we again focused the students' design projects on sustainability; this time, we framed the scenario as relating to the American College and University Presidents' Climate Commitment [30]. Upon becoming a signatory, one of the first tasks a university agrees to take on is conducting an emissions audit. Although Purdue University is not (yet) a signatory, we proposed that students should design a procedure by which building/systems managers could calculate the energy footprint of their building/system, and then use that procedure to calculate a rough estimate of the energy footprint of the systems they had chosen. The project combines a focus on the content and context of sustainability with the real context of the clients of the scenario (referring to local staff and student groups who support the university becoming a signatory) and the real utility of having such a reusable, modifiable procedure.

The project has been broken into 7 milestones (M):

M0: Project description: introducing the scenario of the ACUPCC, the need for an emissions audit, the need for a procedure to estimate the energy footprint of each system/ building, and the timeframe for the remaining milestones;

M1: Problem definition: using brainstorming, needfinding through interviews of each team-member's interests in engineering, and the development of specific, measurable criteria, student teams select a system they would like to develop a procedure for.

M2: Team plan: the teams brainstorm and develop goals and criteria for a good procedure and estimate, then develop a plan using flow-charting and other project planning tools to collect the information needed and develop the design for the procedure.

M3: Information and appendix TOC: To calculate the estimate of the energy footprint of their chosen system, students need to collect (reasonable and reliable) data off the internet, through site visits, through conversations with experts or staff, through other published information sources, and through estimation techniques.

M4: Draft procedure: Student teams develop a first iteration of the procedure the system manager of their chosen system would need to conduct to calculate the energy footprint of that system.

M5: Quantitative estimate: Using the information collected through M3, student teams need to try to follow their procedure to calculate an estimate of their system's energy footprint. In some cases, this means simplifying the M4 procedure to take into account different access to information and time available to dedicate to the estimation/calculation.

M6: Peer-review of the procedure and estimate. Student teams bring drafts of both M4 and M5 to lab, where they conduct a face-to-face peer review of another team's procedure and estimate. Feedback is provided via a rubric and open ended questions, as well as orally. Student teams modify their drafts as appropriate and write a response to explain their iterations.

M7: Final draft and estimate. This final draft is submitted immediately before the last lab period; while the student teams are engaged in other work, the TAs collate all the final drafts and estimations into a table. The table helps see which teams chose identical or similar systems; the TAs can then facilitate a discussion about what factors went into the different designs that made the estimates different. The TAs also help the students discuss the coverage of their collective estimates over the whole of campus, and what they would do differently if the scenario context were to be different. Students will complete a final reflection on the project by the end of lab.

Finally, we revised our grading rubric based (in part) on the rating scheme developed for this paper, and have added in new classroom content and an assignment on information literacy to help students better judge the trustworthiness of sources they uses to justify their design rationales (items 1 and 2 of the rating scheme).

6. CONCLUSIONS AND IMPLICATIONS

In considering the three cases that we presented, in addition to the additional 55 memos that we reviewed, the first-year engineering students that participated in this course considered a wide range of possibilities for making changes to their living spaces to make their living spaces more sustainable. In writing up their final memos, the teams demonstrated varying engagement in engineering design activities. Some teams more explicitly identified their goals, criteria and constraints in their final memos (while nearly all teams engaged in this activity for their first milestone deliverable—M1), the teams engaged in varying information gathering activities, as evidenced by their use of citations, the teams demonstrated varying mathematical modeling activities, and varying considerations of 'second-order effects' that could affect the feasibility of their solutions.

The insights gained from these case studies inform continued improvement of the course material and course activities. We believe that these insights can also benefit other instructors and universities that are (or have already) developed or adapted materials to integrate sustainability into engineering/design education. In particular, our case studies of first-year engineering student sustainability design projects can (a) provide evidence that it is possible, and even feasible, to introduce sustainability to first-year engineering students and (b) provide information that can allow educators to take an informed, learner-centered approach [31] to designing activities or first-year engineering students.

Specifically, the educational and research activities that we have conducted, including our own reflections on our practice, lead us to a few principles for 'normalizing sustainability' in the context of first-year engineering:

- sustainability should be presented as a fundamental aspect of engineering practice, not something that is considered as an afterthought or practiced by a small subset of engineering practitioners;
- sustainability can be effectively integrated with engineering design, which is a central aspect of engineering practice common to all engineering disciplines [32];
- in addition to explicitly addressing sustainability concepts as well as design skills, first-year engineering courses also need to include educational activities that help students adopt information literacy skills for students to learn to practice sustainable design;
- students also need to participate in activities that help them understand, anticipate, and account for 'second-order effects';
- students also need to understand the need for engineers to both consider and articulate economic arguments while at the same time considering and articulating non-economic arguments (the triple bottom line).

We see this list as a starting point to build upon. As we further design and re-design the educational activities that we include in our courses, reflect on our teaching practice, and conduct additional research, we anticipate that we will contribute further insights and principles for sustaining 'normalized sustainability' in engineering education. Beyond this, other educators world-wide are considering this issue as well, including the authors of the other papers in this special issue. We enthusiastically look forward to the growth of a body of work that will enable us as a community to effectively sustain sustainable design education.

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APPENDIX A: RUBRIC USED TO ASSESS AND GRADE FINAL MEMOS

Rubric item	Proficiency levels	Score
Message: The explicit message about sustainability is desirable and clearly articulated.	Level 2: Explicit message is desirable and understood in less than 30 seconds. Level 1: Explicit message is desirable and understood in less than 1 minute. Level 0: Explicit message undesirable or takes more than 1 minute to understand.	
Message: Implicit messages are desirable for the client.	Level 2: The language is gender-balanced and racially-balanced or neutral and does not reveal a limited view of sustainability. Level 1: One or more implicit messages may be troublesome. Level 0: Implicit message could offend certain clients.	
Technical content: Goals and constraints.	Level 2: Goals and constraints clear, measurable, and addressed in memo. Level 1: One or more goals or constraints may not be clearly measurable. Level 0: Few goals or constraints are clear or measurable or memo recommendations are not connected to goals or constraints.	
Technical design: Evidence.	Level 2: Supporting material provides convincing evidence for important assertions made in the memo. Level 1: One or more important assertions (or assumptions) are unsupported. Level 0: Memo and supporting material are not convincing.	
Memo: Connection to the client.	Level 2: Client choice sensible, memo addresses their concerns, assumptions articulated. Level 1: Client choice sensible, but how the memo addresses their concerns is not completely clear. Level 0: Client choice is unclear.	
Memo: Connection to society.	Level 2: Secondary costs (to others, to society) clearly articulated. Level 1: Secondary costs considered at least implicitly. Level 0: Secondary costs are not considered or recommendations would have pathological consequences.	
Memo design: The memo stands alone without verbal explanation.	Level 2: Memo stands alone, the sustainability plan is clear. Level 1: Memo stands alone but the reader has to struggle somewhat to understand the sustainability plan. Level 0: Memo cannot be understood without explanation.	
Memo design: The viewer understands the flow of information.	Level 2: Information flow is clear, memo is readable and free from distracting elements. Level 1: Information flow can be figured out; memo can be read in spite of distracting elements. Level 0: Memo unreadable or dominated by distracting elements.	
	TOTAL	/16

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