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Introduction of Sustainability Concepts into Industrial Engineering Education: a Modular Approach

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ABSTRACT

Sustainability in operations, production, and consumption continues to gain relevance for engineers. This trend will accelerate as demand for goods and services grows, straining resources and requiring ingenuity to replace boundless supply in meeting the needs of a more crowded, more prosperous world. Industrial engineers are uniquely positioned to incorporate sustainability concepts into this work; their focus is on systems, and in observing these systems at a high level, they can most effectively choose which parts of the systems to modify to produce desired results.

In this paper, we explore using the vehicle of education to introduce sustainability concepts into industrial engineers' training. We first survey the current state of sustainability education in industrial engineering programs. We then discuss a curricular modification program in which sustainability was introduced into several courses through use of content-focused modules. We conclude with our recommendations on how such a structure can be used to expand sustainability education in industrial engineering programs at all levels.

Key Words: Sustainability, Industrial Engineering, Curriculum

INTRODUCTION

The Earth has a finite amount of resources available for human use. Within the span of recent decades, the pace at which these resources are used – in many cases, consumed – has increased dramatically. At present, the totality of human civilization is putting a greater burden on the planet than its regenerative capabilities can sustain. Allowed to continue unchecked, this process will necessarily deplete finite resources to the detriment of both the global ecosystem and humanity.

As such, the concept of sustainability – organizing processes in ways that reduce their consumption of resources and negative impacts on society and the environment – grows more and more significant as humanity's collective processes increase in number and complexity. Incorporating sustainability into these processes reduces resource consumption, and each instance in which sustainability reduces this consumption lessens the burden on the Earth. Widespread adoption of sustainability, though, is difficult for a number of reasons. Most fundamentally, sustainability requires consideration of multiple objectives – reductions in consumption, minimization of negative externalities, lessening burdens on future generations – that can seem at odds with an immediate-term economic profit motive. A narrow-minded focus on this single objective will only continue to exacerbate the current dilemma; by broadening objectives to include the concept of sustainability, processes can be reformed to improve their utility to different parties over different spans of time.

These 'processes', generally, encompass the activities by which human civilization sustains and advances itself. They include everything from resource extraction and transformation into finished consumer goods, to transportation of people and materials, to the generation of electric power, heat, and light; in short, all consequential human activity contributes in one way or another to a process, and is suitable for consideration in light of sustainability. Industrial engineers have the unique task of organizing and optimizing these processes. While others are concerned with the particular inputs and outputs of systems of processes, or the mechanics by which they function, industrial engineers study and improve these systems themselves. By designing a supply chain to get components to a manufacturer in time for assembly, coordinating the delivery logistics of perishables, or determining the optimal blend of finished goods to produce from a collection of raw materials, industrial engineers 'connect the dots' between beginnings and endpoints with a view towards all aspects of the system and their collective interplay.

Given this perspective, industrial engineers are uniquely suited to address the need for the greater implementation of sustainability in the systems that underlie daily life. By examining the needs of a process or system at each point within it, with a view towards the ultimate goals to be achieved – including the goal of sustainability itself – industrial engineers can alter different parts of the system while also managing its outputs to keep the entire enterprise successful. Their panoptic perspective and ability to affect the system at different points afford industrial engineers real opportunities to introduce sustainability across a broad range of applications.

Industrial engineers have generally been trained to work towards the maximization of economic profit. While effective in achieving this objective, the tools of the field can also be employed in the service of other goals that have been less frequently considered in the past. These other objectives (like minimizing resource consumption, or maximizing the health of a population) can be combined with the profit objective to achieve sustainable systems and processes that still accomplish their economic goals. In order to be able to make the changes that their abilities and roles allow, however, industrial engineers must have some awareness of these opportunities; they must also know how to apply their skills to problems from perspectives beyond a unitary focus on profitability.

The best way to achieve this transformation in mindset, and to prepare industrial engineers to implement sustainability in their careers, is through their education. As we will show, sustainability is just beginning to enter into undergraduate and graduate engineering curricula in the United States. There are many opportunities to introduce concepts of sustainability and information on how to achieve it through the tools industrial engineers employ; taking advantage of these opportunities, especially those early in a young engineer's educational career, gives more time for these concepts to take root and influence the engineer's later behavior. Through a pilot program at a large public university in the Southeast conducted over several years, we attempted to accomplish this goal of introducing sustainability concepts into engineers' education through the implementation of sustainability modules into the industrial engineering curriculum. We present our findings below, and generalize them to suggest a process by which sustainability concepts can be effectively incorporated into industrial engineering education.

STATE OF AFFAIRS

Having established the importance of introducing sustainability concepts into industrial engineering education, we examined the extent to which these concepts are already integrated into the curricula at universities. We chose to analyze programs ranked in the top 30 in the Industrial/Manufacturing/Systems Engineering ("IMS") 'graduate' category by U.S. News & World Report [1]. While not exhaustive, this list of programs was compiled using assessment surveys completed by the heads of industrial, manufacturing, and systems engineering departments at 91 institutions. As such, it is a reasonable proxy for the group of programs with the best reputations amongst their peers in the nation. In the ranking, each institution is given a score, on a scale of increasing reputation peaking at 5.0; the institutions we considered have scores ranging from 4.8, for the highest-ranked institution, to 3.0 for the lowest. The average score is 3.67.

Our analysis focused first on the opportunities available to undergraduates. By examining department and university websites, course listings, and other similar, publicly available sources, we sought to determine:

1. Whether a minor or certificate program was available in sustainability, or in a reasonably related field;
2. The number of undergraduate courses in the IMS department with sustainability concepts incorporated, if any; and
3. The number of courses with a primary focus on sustainability itself that incorporated IMS concepts, if any.

In choosing this approach, we aimed to determine the extent of interplay between sustainability and IMS engineering concepts. In examining formal options (minors or certificates) available to students in sustainability, we sought an understanding of institutions' willingness to grant official recognition to a structured, focused sequence of study on the topic. We used a holistic method to perform this study, searching available information for keywords, descriptions, and topic emphasis relevant to the sustainability concepts discussed at length later in our analysis. In general, a stated focus on either sustainability or directly relevant subconcepts was required for inclusion in our tabulation. Discerning whether sustainability was the primary focus of a relevant course, or a secondary one, was somewhat subjective; we made such decisions based on course descriptions and syllabi, where available.

Several interesting results are apparent in the data presented in Table 1. First, half of the programs considered offer formal certification after completion of a course of sustainability study, and half do not. The average score of programs offering such certification (3.69) is very close to the overall average score (3.67) of all programs surveyed, and indicates that formal certification in sustainability does not correlate highly with program rank. Second, only a third of institutions offer IMS courses with sustainability content; these institutions are clustered higher in the rankings, with an average

	Yes	No	Avg. Score	Avg. No. of Courses Offered
Minor/Certificate Available	15	15	3.69	*N/A*
IMS Courses with Sustainability Content	10	20	3.90	1.6
Sustainability Courses with IMS Content	2	28	3.15	4.5

Table 1: Availability of undergraduate-level sustainability education at 30 highly-ranked IMS programs in the U.S. (adapted from [1])

	Yes	No	Avg. Score	Avg. No. of Courses Offered
Masters in Sustainability Available	3	27	3.30	*N/A*
Doctorate in Sustainability Available	1	29	3.20	*N/A*
IMS Courses with Sustainability Content	8	22	4.20	3.3
Sustainability Courses with IMS Content	1	29	3.20	6.0

Table 2: Availability of graduate-level sustainability education at 30 highly-ranked IMS programs in the U.S. (adapted from [1])

score of 3.90. The number of such courses offered differs substantially among institutions, but averages at 1.6. Finally, almost no programs offer sustainability courses with IMS content. Arizona State University is a significant exception, with at least eight such courses (including *Mathematical Concepts and Tools in Sustainability, Energy Use and Conservation*, and several others).

As is evidenced in Table 2, the situation is both similar and more extreme at the graduate level. Very few formal degree options are available; Arizona State University is the only institution to offer a Doctorate in Sustainability, and it is joined by George Mason University and Columbia University in offering a Masters in the field. Only eight institutions offer IMS courses with sustainability content. These cluster at the upper end of the rankings to an even greater extent than was the case at the undergraduate level, with an average score of 4.20; on average among these institutions, more than twice as many such courses are offered at the graduate level than at the undergraduate level. Only Arizona State offers sustainability courses with significant IMS content.

While course offerings and programs are in a constant state of flux, and could change for the better at any time, these results demonstrate the relative paucity of options available to students interested in IMS who also wish to explore sustainability. Course offerings are relatively infrequent and scattered, and there are nearly no options for graduate students looking to devote themselves fully to an education in sustainability. Arizona State is the only institution among the 30 studied to offer a comprehensive, multifaceted education emphasizing the interactions between IMS and sustainability content at all levels of sophistication. Its School of Sustainability, established in 2007 and part of the broader Global Institute of Sustainability, is truly a leader in integrated sustainability education and research.

In addition, the instances in which sustainability has been systematically introduced into IMS coursework are concentrated among the institutions at the top of the rankings. In practice, this may restrict exposure to these concepts to a subset of students, and significantly reduce the dissemination of sustainability concepts through the IMS education channels into eventual practice. This uneven distribution heightens the need for a method of introducing such concepts into IMS education that is robust, flexible, and appropriate for multiple applications at diverse institutions.

In considering literature relevant to our study, we first examined how other researchers conceptualize sustainability, its content, and its boundaries. Kates et al. [2] provide an overview of attitudes towards the concept of sustainably development. They expand upon the Brundtland Commission's 1987 definition ("to ensure that [development] meets the needs of the present without compromising the ability of future generations to meet their own needs"), and analyze how sustainable development can be defined through its goals, indicators, values, and practice. Ultimately, they argue, the definition itself is expansive and fluid, and will evolve as the fields with which it interacts incorporate it further. Glavič and Lukman [3] provide an extensive categorization of terms relevant to sustainability, especially as relevant to the domains of science and engineering. They organize the concept into the domains of sustainable systems, sub-systems, approaches, and principles, situating the most important topics in each domain relative to four overarching themes: policy, society, economy, and environment. With more extensive exposition on the content contained within the sustainability concept, Lehmann et al. [4] examine the usefulness and shortcomings of a mechanism to examine technologies and, by extension, engineering applications with respect to sustainability: the Social Life Cycle Assessment (SLCA) method. They conclude that though the method is still lacking in consideration of several relevant dimensions of social sustainability, particularly with respect to different environments of technology introduction, it is a useful comparative tool in attempting to parse sustainability concepts and objectively link them to practice. Further explorations of this mechanism, combined with the definitions of sustainability addressed by others above, should provide ample opportunity for the categorization and ranking of appropriate topics for different educational and practical settings.

Finally, White [5] takes a different approach entirely to the issue of defining sustainability. Recognizing the fundamental difficulties in pinning down the concept – and the benefits of allowing the definition to remain somewhat fluid – he utilizes a tag-cloud method to analyze different published definitions, resulting in "a visually-appealing ménage of terms providing a composite picture of the essence of sustainability." Ultimately, this kind of crowdsourced, concept- and keyword-focused definition mechanism may be most appropriate in capturing those aspects of sustainability most present in and relevant to the work of the greatest number of researchers, investigators, and practitioners.

We also examined recent literature addressing best practices for modifying curricula. Galambosi and Ozelkan [6] present a thorough overview of the state of the field as of 2011, with respect to both general engineering and management curricula. A number of other recent works detail modular approaches explicitly. Perhaps most closely related to our own work, Xue [7] describes a module he used to introduce micro- and nanotechnologies to mechanical engineering students. As with our modules, Xue adapts a concept related to but distinct from the traditional curriculum in his field to fit directly into the material students are already studying. Similarly, Castles et al. [8] describe their introduction of a module on mechatronics – a topic incorporating aspects of mechanical, electrical, and computer engineering – into the first-year engineering students' curriculum. As is often the case with sustainability, Castles and his co-authors explicitly sought to emphasize interdisciplinarity and collaboration in constructing and implementing their module. Joyce et al. [9] address sustainability explicitly through a module introduced in a mechanical engineering setting, and place particular emphasis on lessons learned from students' reactions to its introduction. In particular, they highlight that in order for these kinds of modular additions to the base curriculum to be successful, students must view the topics and projects as authentic and relevant to both their educations and their future careers in practice. Finally, Pierre et al. [10] offer an alternate use of modules as stand-alone curricula for mini-courses, in their case in the electrical and computer engineering domain (with an intent to introduce students to a broad range of ECE topics). Though our own project was not developed along these lines, this idea represents an interesting alternative use of the module concept.

Finally, we conducted a review of a number of papers addressing sustainability content in education in different engineering disciplines. Allenby et al. [11] provide a recent overview of the topic, with information on content considered, funding sources, and relevant educational tools; they also address the tension between sustainability as a frequently (or even necessarily, as discussed above) 'fuzzy' concept, and engineering as an exacting field. Murphy et al. [12] also provide an overview, and conduct an analysis of how much sustainability content versus traditional content is present in different programs at a number of universities that parallels, in several ways, our own.

With respect to specific disciplines, the fields of chemical engineering (Allen, Murphy et al. [13], Allen and Shonnard [14], Sheehan et al. [15], etc.) and civil engineering (Elleithy and Lau [16], Perlinger et al. [17], Moreno et al. [18], Watson et al. [19], Sullivan and Walters [20]. etc.) seem particularly well served in the literature; a substantial body of work connects these fields to sustainability in an education context. More generally, several authors suggest the need for more of this integration across engineering disciplines (Hawkins et al. [21], Aurandt et al. [22]). A particular emphasis is placed on environmental and ecological engineering (Biswas [23], Cervantes [24]) as a natural branch of engineering from which sustainability can grow into other disciplines. Kalla and Brown [25] suggest sustainability modifications to the manufacturing engineering curricula, and Lynch-Caris and Sutherland [26] explore the justification for advancing sustainability through industrial engineering education; they emphasize the significance of industrial engineers' unique skill sets and competencies in addressing issues of sustainability. In general, this emphasis deserves greater expansion in the literature, and as industrial engineers, we believe our field still has much to contribute alongside other engineering disciplines in the integration of sustainability content into the curriculum.

Our work builds upon these recent studies by laying out a systematic approach to introducing specific sustainability concepts into industrial engineering education in a structured, repeatable manner using modules. We developed such an approach to test the feasibility and effectiveness of actual curriculum modification, and studied its implementation at the University of Central Florida. This work is the subject of the remainder of our discussion.

PROGRAM OVERVIEW

The formulation and execution of our proposed curricular modifications were carried out with support from the National Science foundation, and its Division of Undergraduate Education. The original grant application was a joint effort of the faculty co-authors and originated in their shared interest in the intersection of sustainability and industrial engineering education.

To begin the process of introducing sustainability concepts into an IMS educational setting in a repeatable manner, we first defined the goals we hoped to accomplish through the enhanced curricula. We sought

> *"to provide industrial engineering students...with multiple exposures to what it means to have a sustainable mindset and to facilitate the development of both the passion and the skills to integrate industrial engineering tools and methods with sustainable practices."*

In considering these broad goals, we then refined the scope of our proposed work by laying out specific objectives we hoped to achieve through curriculum modification. In choosing objectives, we sought goals that could be measured through both quantitative assessments (quizzes) and qualitative evaluations (surveys and focus group). The objectives chosen were:

1. Increase students' understanding of concepts in sustainability.
2. Infuse selected industrial engineering courses with new innovative material targeting sustainability issues that relate to the nature of each revised course.
3. Improve students' appreciation of the impact of industrial engineering solutions on the environment and society.
4. Improve students' abilities to integrate industrial engineering tools and methods with sustainable practices.

'Infuse', as used in our second objective, is a key term here. While the other objectives relate to the outcomes of our curriculum modifications with respect to student learning and development, we formulated this second objective to reflect both our desire to introduce concepts of sustainability into the curriculum as well as our understanding that such a process would necessarily be an infusion over time, rather than a sudden, dramatic shift in focus, direction, or content. As has been demonstrated by Peet et. al. [6], for example, there can be significant opposition amongst instructors to top-down, imposed modifications to curriculum. Changes that are made in consultation with instructors, however, tend to generate far less friction and are ultimately more successful in achieving their aims. As such, we concluded that an organic process – one in which sustainability was introduced in a measured fashion, rather than all at once, into the curriculum – was most likely to satisfy our objectives without alienating stakeholders in the process.

To determine the courses most appropriate for the introduction of sustainability content, we first classified the courses offered in industrial engineering at our university into two groups: "those that teach methodologies and tools to help in problem solving, e.g. Operations Research", and "those that introduce new concepts along with the appropriate models and methods, e.g. Facilities Planning". In doing so, we were driven by a need to determine the best ways in which to match sustainability concepts with the material covered in existing classes. Courses of the first kind would be most appropriately modified by adding sustainability content – for example, an environmental optimization metric in Operations Research – for the students to approach using the tools already covered in the curriculum. The second category of courses, in which key IMS concepts like inventory management and production planning are introduced, provides an opportunity to fuse sustainability directly with these concepts. Through modification of both types of courses, we hoped to both familiarize students with sustainability in seamless union with existing core content, and to show them how to use the tools of their field to work with it effectively. Using this initial survey of courses, we decided which sustainability concepts would be most appropriate for each; the results of this determination are presented in Appendix A.

We then developed a list of actual sustainability concepts we wished to address through modules in IMS courses. We focused on ideas that are most relevant to the aims of sustainability, as well as most appropriate for combination with IMS coursework; we wanted to give students exposure to both the ideas and the tools most useful today in advancing sustainability in practice. These areas of focus (details in Appendix B) were:

- Life Cycle Assessment
- Design for Sustainability
- Total Quality Environmental Management
- Environmental Management Accounting
- Green Supply Chain Management
- Product Recovery
- Sustainability Performance Metrics

With a categorized set of existing IMS courses with which to work, and an established group of sustainability concepts to introduce into these courses, we examined each course in detail to determine the most appropriate curriculum modifications to make. We considered synergies between existing course content and relevant sustainability content (for example, introducing ideas of green packaging to logistics courses), and focused on the distinction between concentrations on methods and on new ideas. This process allowed us to build concrete links between courses available, and content appropriate for introduction into them. The complete results of this process can be examined in Appendix C.

Once sorted in this way, we expanded our sustainability concepts to modules. Our intention was to develop a 'microcurriculum' that could be taught, by an instructor expert in the material, in one or two class periods; for the purposes of our pilot program, modules were developed specifically for courses we taught. We also included evaluations, in the form of a short quiz, at the end of modules to test understanding. For example, we expanded the topic of Green Supply Chains into the module structure:

1. Interaction between manufacturing and the environment
2. Green supply chains and green supply chain management
3. Closed-loop supply chains
4. Why 'green' the supply chain?
5. Environmental legislation
6. Environmental metrics
7. Examples of green initiatives' impact on supply chain management
8. Industry examples

Assignment: In-class quiz in the next lecture covering the topics above

In organizing the material into this structure, we sought to incorporate the relevant sustainability concepts as tightly as possible into industrial engineering issues. We began by considering how these two spheres interact – the connection between manufacturing and the environment – and explained how this connection can inform a modification of how supply chains are designed and operate. Having addressed the 'what', we then focused on the 'why', and explained the process, financial, social, and legal benefits of implementing the kinds of changes proposed. We then addressed how the success of these changes can be measured, and concluded with concrete examples of how these kinds of changes are being implemented in actual practice.

We introduced this module into a course on production and distribution systems, which is concerned with decision rules in industrial environments including forecasting, production planning, scheduling, inventory control, and project monitoring (see module presentation sample, Appendix D). The module was completed in one class period, and was inserted into the portion of the course concerned primarily with supply chain management in general. In this manner we were able to both build on students' expanding understanding of supply chains, and to introduce relevant sustainability concepts early enough in their curriculum to blend these concepts with the usual course content.

Over the course of our two-year program, we continued developing sustainability modules and introducing them into existing IMS coursework. We measured the outcomes of this effort by using quizzes to test content understanding, and surveys to examine student perceptions and reactions; these results are discussed more fully in the next section. In addition, towards the end of our study we developed a standalone course entitled 'Sustainability in Engineering'. This course will be offered to all students in the university's Honors College starting in 2015, and is concerned with

> *"the principles of sustainability in industrialized systems; the use of systems analysis and lifecycle assessment in design of industrial systems; the development of sustainability metrics and indicators; and the fundamentals of natural ecosystems as models for the design and operations of industrial systems." [course description]*

This course has sustainability as its core, rather than IMS concepts; it is the inversion of the approach in which modules are introduced into existing IMS courses, and represents the next level of sophistication in developing a robust sustainability curriculum that is fully and coequally integrated into IMS education. Ultimately, our goal is the successful implementation of both approaches – IMS courses with sustainability content, and sustainability courses with IMS content – to enhance education in both areas.

EVALUATION METHODOLOGY AND RESULTS

To test the effectiveness of the sustainability modules we introduced in meeting the goals and objectives specified in the previous section, we used several methods. Our intent was to gain some sense of the students' understanding of the material presented in a quantitative way, while also registering their qualitative impressions about the information, the process, and the value they believed was added to their education.

To accomplish the first of these aims, we assessed students at the end of two modules with quizzes on the material introduced; for one of these modules, the students also completed a writing assignment (see Appendix E). In the course on productions and distribution systems, with 54 students in Spring 2011, we incorporated our Green Supply Chain (GSC) module. In the same course, we introduced a module on Humanitarian Logistics (HL) (see Appendix F for further demographic information on the students in these classes). Nearly all students achieved high scores (90% or higher) on the quizzes for their module; the class average for GSC was 93%, while for HL it was 91%. In addition, the average grade on the HL term paper assigned in the industrial facilities course was 96%. While these results are limited by the small sample sizes and single applications of performance evaluations, they demonstrate that students exposed to the modules did absorb a significant amount of their content. Furthermore, students' performance on the HL term paper evidences their ability to recall, expand upon, and synthesize information they first experienced in the module over the longer term.

Given that the primary aim of our effort was to introduce concepts of sustainability to IMS students, the qualitative assessments they completed give a more complete measure of our success. To carry out this assessment, we asked students to complete end-of-course surveys at the conclusion of the semester (see Appendix G for a sample survey). We also convened a focus group, comprised of students from both courses, to examine their impressions of both the specific modules introduced and the more general concept of using them to modify the curriculum. These assessments were carried out by the Program Evaluation and Education Research Group, an independent center at our university, to prevent bias in gathering student response data. The specific methods of evaluation are detailed in Appendix H.

Responses to our surveys were mixed but positive. In particular,

- Between 94% and 100% of the students agreed ('Agreed' or 'Strongly Agreed') that our modules developed their understanding of new applications of industrial engineering
- Between 88% and 100% of the students said that they were left with "a sense of excitement" about their intended career paths and their abilities to impact society as industrial engineers
- More than half of the students expressed interest in pursuing a Senior Design Project involving one of the sustainability concepts addressed
- All the students (100%) indicated that our presentations increased their awareness of issues and challenges in each of the areas presented

The focus group allowed us to examine in greater detail the students' reactions to our work, and we encountered a more nuanced optimism about the topics and process of teaching them. Students' primary concern was that modularized introductions to material simply do not provide enough exposure for the material to be useful to them:

> *"There is room in our classes for this topic to be touched on, but having an elective [a whole course] would be better."*
>
> *"Having a more in-depth look at [the concepts] would add more…I definitely thought that from that one lecture, you could see that students were more engaged with the relevant issue."* [quotes from students in focus group]

Even so, as the latter quote demonstrates, a brief introduction to sustainability material can spark students' interests in the topic. The participants in our focus group also recognized the benefits of greater exposure to this material, both for their education and their careers:

"If they had a whole course, I could put it on my résumé."

"It would be a good elective; it broadens the mind of the engineer."

Most encouragingly, students seemed enthusiastic about the possibilities that IMS affords them to make an impact with respect to sustainability. Their comments illustrate their awareness of possibilities to carry our IMS work in a sustainable context, and to use their education and careers to further the goals of a more sustainable future:

"When I got into this, it wasn't even on my brain to think, 'Oh I can save the environment by being an industrial engineer,' so by seeing that it opens a door…I can go down that way, and I can be socially conscious, and I can make a living off being an industrial engineer. So you kind of get both worlds."

"As an industrial engineer, I think we have a lot to provide society, because we are getting the skills on how to do things more effectively and more efficiently, so we are not reinventing the wheel, we are just making the wheel a little better. If we can do this with the concept of how can we do this and *protect the environment at the same time…because any environmental movement that is not profitable, is not going to be picked up in the commercial world. If the company cannot do it and be profitable, the company is not going to exist."*

"As far as coursework I found it more relevant and it [the use of a real-life problem] communicates better [for learning]. It made questions and problems more relevant. In operations research as well, not just supply chains…for example, if you need to evacuate because a hurricane is coming, these roads can only handle so many people, so how do you negotiate traffic and have a route set? It is easier for me to pay attention and learn it if I am more interested in it. My generation is more conscious of what kind of knowledge I want to hold on to."

More examples of students' responses are available in Appendix I. Their overall message is clear: students recognize the importance of sustainability, both for its intrinsic merit and to their future careers, and want to learn to approach it with the tools of their chosen field. This attitude suggests that, if properly implemented, the infusion of sustainability content into the IMS curriculum can make a real difference in affecting students' perspective on the material – and, ultimately, in their ability and willingness to work with it in practice.

Though we did not conduct a formal evaluation of the attitude of the faculty towards our modules, our impression was that their reaction was very positive. In general, both faculty in the department and the administration of the School of Engineering were supportive of our efforts. The administration, in particular, saw synergies between sustainability in the curriculum and broader institutional efforts to expand the university's sustainable practices. Exploring these synergies can lead to greater opportunities for students to see concepts in practice, and can give them the chance to begin applying both portions of their education – IMS, and sustainability – in an integrated manner while still in school.

LESSONS LEARNED: PROGRAM STRUCTURE

The modules we introduced in several classes at UCF were effective in accomplishing our original objective: the introduction of sustainability content into IMS courses. More generally, an expanded and comprehensive approach to integrating sustainability into the curriculum would involve both this step, and the introduction of independent courses wholly devoted to sustainability as a core concept. In this manner, balance is achieved between IMS and sustainability material; this material should also be presented in a manner accessible to students throughout their educations, allowing them to encounter it early and to synthesize it as a fundamental part of their training.

Our experiences, and the responses our initiative generated from students and faculty, have led us to a number of conclusions regarding how to design and introduce a sustainability-centered curriculum into an IMS department. These suggestions are appropriate at both the undergraduate and graduate level; indeed, we believe the most effective curriculum modifications will involve seamless and comprehensive modifications at both levels.

Modular Curriculum Development

To introduce sustainability into IMS instruction, existing courses and syllabi must first be surveyed to determine the best candidates to receive different sustainability concepts. At this survey stage, the member of the faculty driving the sustainability initiative must engage actively with instructors to further establish class environments in which sustainability concepts can be most effectively introduced. After identifying these classes, appropriate modules focused on applicable concepts should be developed and merged with the rest of the course content, as was done in our pilot program.

Standalone Course Development

Pivoting from modular sustainability elements embedded in IMS courses, standalone classes focused on sustainability as the core subject of study should then be developed. These courses should, in a sense, be the inversions of those in Phase 1; rather than IMS material being central, and sustainability material being peripheral, primary emphasis should be reversed. With such courses in place, students have the opportunity to access sustainability at different degrees of instructional intensity. These courses would come later in students' educational paths (perhaps as upper level electives) to complement early work that discussed sustainability tangentially. Most importantly, these courses would allow students to address the intersection of sustainability and IMS from different directions and perspectives. Doing so accomplishes the goal of making sustainability a fundamental and integrated element of their IMS education.

Expansion of Sustainability Activities

As an advanced step, departments can also choose to concentrate explicitly on expanding their focus on sustainability through research and augmented engagement with industry and the university as an entity. This necessary level of commitment to sustainability concepts is not yet widely implemented, but represents the next stage in the development of integrated, comprehensive IMS education. This kind of education could take shape through design projects, capstone courses, faculty-student research initiatives, and collaboration with industry focused on sustainability as the core motivating concept channeled through engineering practice. Making such a commitment to these kinds of initiatives requires significant resources, and strong collaboration with university administration. In providing opportunities for research, collaboration, and further study, however, programs developed to this level will truly give students the chance to experience a fully synthesized IMS-sustainability environment. Such an environment offers them the most comprehensive education, and the best training for their subsequent careers.

In working through these steps, several principles stand out as particularly relevant to their successful execution. We have grouped these into three primary areas.

LESSONS LEARNED: PRINCIPLES

Consultation

At each stage of the development and implementation of a sustainability curriculum, constant contact with all relevant parties is vital to the success of the endeavor. Maintaining productive communication with faculty, members of the administration, and students themselves – through surveys, informal study groups, and general awareness of their reactions to ongoing efforts – ensures a smoother and more effective curriculum modification process. In addition, consultation with those outside the immediate departmental environment can help to broaden perspectives and make the educations students receive more relevant and directly connected to the ultimate application of this education. In particular, consultation with members of other departments on campus, as well as with members of the business community that traditionally interacts with IMS are important. Such consultation will provide fruitful opportunities for maximizing the effectiveness of sustainability curricula in its applications.

Gradual Change

In addition to drawing on multiple sources and remaining in open communication with different parties throughout the process of developing and integrating sustainability curriculum, the process itself cannot occur all at once. Such change can be disruptive and disorienting, and by trying to do too much too fast, those developing the modifications risk alienating others in the process. We believe our tiered approach – first modules, then standalone courses, and finally full-fledged research and sustainability engagement activities – is an appropriate and effective one in which change is meaningful but not destabilizing. Ultimately, this will be the most effective way to accomplish the goals and objectives set out.

Sustained Focus

Perhaps most importantly, a sustainability curriculum initiative cannot move forward in fits and starts. Unfortunately, sustainability has acquired something of a reputation as an ephemeral buzzword disconnected from concrete, well-defined efforts. In seeking to change this perception and make sustainability education meaningful, the effort must remain 'on-message' and keep focused on developing, integrating, and expanding the curriculum throughout the process. This focus is most easily achieved when spearheaded by a faculty member or administrator devoted to the initiative, but could also be maintained through a group of like-minded individuals tasked with driving and supporting change over time; in our case, the collaboration of faculty in our department with an interest in promoting sustainability education provided the requisite momentum. Constant effort will both aid in reaching the goals of introducing sustainability into the IMS curriculum, and help to improve the field's perception in the eyes of researchers, faculty, and industry.

CONCLUSIONS

These suggestions, building on our pilot program, are meant to serve as a basic framework for the development of sustainability curricula in concert with existing IMS education programs.

Variation from them is important, and will provide additional opportunities for the development of best practices. We recognize that our work is limited in scope, but our success in meeting our objectives and the positive feedback we received suggest that our approach is both effective and more generally applicable. The initiative we started is still underway, and continues to expand and enhance students' educational experience.

Ultimately, we hope to see sustainability take root in IMS departments in the coming years. Change must proceed gradually and methodically; given the time it will take, it is even more important that such a process of change be initiated soon. Sustainability is an increasingly essential aspect of our interaction with our world and the processes by which we interact with it. From the perspective of our students' education, as well as their futures, we cannot afford for it to remain ignored for much longer.

ACKNOWLEDGMENTS

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APPENDIX A: IMS COURSES (ROWS) AND RELEVANT SUSTAINABILITY CONCEPTS (COLUMNS)

	Environmental Accounting	Product Recovery	Green Supply Chains	Environmental Quality Management	Life Cycle Assessment	Sustainability Performance Metrics	Social and Environmental Responsibility	Design for Sustainability
Engineering Economic Analysis	√				√			
Engineering Administration		√	√		√			√
Introduction to Industrial Engineering and Management Systems		√	√	√	√	√	√	√
Work Measurement & Design			√					√
Principles of Cost Engineering	√							
Industrial Engineering Senior Design Project	√	√	√	√	√	√	√	√
Industrial Engineering Applications of Computers								
Safety Engineering and Administration							√	√
Human Engineering							√	√
Industrial Engineering Applications in The Service Industries								
Industrial Control Systems		√	√			√	√	√
Industrial Facilities Planning and Design		√	√				√	√

	Environmental Accounting	Product Recovery	Green Supply Chains	Environmental Quality Management	Life Cycle Assessment	Sustainability Performance Metrics	Social and Environmental Responsibility	Design for Sustainability
Manufacturing Engineering					√		√	√
Principles of Concurrent Engineering								√
Computer-Aided-Manufacturing								√
Empirical Methods for Industrial Engineering						√		
Quality Engineering				√	√	√	√	√
Operations Research			√			√	√	
Systems Simulation						√	√	
Probability and Statistics for Engineers						√		

APPENDIX B: AREAS OF FOCUS IN MODULAR SUSTAINABILITY EDUCATION (FROM ORIGINAL PROPOSAL)

1. Life Cycle Assessment

Life cycle assessment (LCA) is a valuable tool in evaluating the total environmental impact of a product or process through every stage of its life. The three major components of life cycle assessment are (Madu 2001):

a. life cycle inventory analysis: the aim is to quantify environmental burden throughout the life of the product, process or service.
b. life cycle impact analysis: concerned with aggregating and interpreting the inventory data for use in managerial decision-making.
c. life cycle improvement analysis: concerned with identifying areas where improvements can be achieved, in addition to tracking the product through its life cycle to detect areas for continuous improvement.

2. Design for Sustainability

Design for sustainability (DfS) is a broad effort to consider both environmental and socio-economic systems during design (Fiskel 2003), in which we try to modify the controllable characteristics of our designed artifacts (e.g., factories, products) in ways that create environmental and social benefits. DfS encompasses LCA and the more known design for environment (DfE). While LCA can be used to identify ideas for redesign to affect reductions in environmental impact, its traditional application has been after a product has been designed and produced (Sherwin and Bhamra 1999, Nagel and Stevels 2003). DfE involves introduction of environmental considerations during the design phase of a product or service. Popular design strategies under DfE include: design for recyclability, design for maintainability/durability, and design for pollution prevention (Madu 2001).

3. Total Quality Environmental Management

Total Quality Management (TQM) can be used as a tool for monitoring the effectiveness of any implemented opportunity; with the environment as an element of TQM, the name TQEM is a natural extension. A TQEM system can reduce overall cost in the company and supply chain, and eliminate waste and wasteful practices (Harland 1996).

4. Environmental management accounting

Environmental management accounting answers questions such as: What are the environmental costs? How does one find their causes? How does one assign these costs? The purpose is to manage costs while directing and focusing the company to act in a positive way towards the environment.

5. Green Supply Chain Management

Green Supply Chain Management (GSCM) can be defined as integrating environmental issues into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the customers, and managing the product after its useful life (Srivastava 2007). The latter is usually encompassed within Product Recovery Management (discussed next). Wang et al. (2005) suggest that the GSCM's objective is to make the material flow value-added by balancing and controlling the material, capital, information, and work flows of the Green Supply Chain (GSC), without losing the traditional goal of providing high quality products and services to customers with fastest time-to-market, lowest cost and environmental impact.

Designing and operating GSC involves an abundance of topics that are traditionally addressed within IE courses from simplified product design for easier disassembly, utilizing recycled materials; reducing energy consumption through efficient transportation; simplified and energy efficient facility layouts; reduced work-in-process and scrap; and collaborative relationships with customers and suppliers to streamline the supply chain and minimize waste (Fiskel 2003).

6. Product Recovery

Product recovery involves the management of products once they have reached their end of life (EOL). The operations consist of several sequential activities (Toffel 2004): collecting the products (reverse logistics); determining the potential for the product's reuse, disassembling the product, and segregating valuable components from scrap, remanufacturing components, recycling materials, and disposal of residuals.

There are a myriad of issues within product recovery that can be addressed in IE courses: In the field of supply chains, the relationship between suppliers, manufacturers, retailers and recyclers can be revised; should manufacturers contract with recyclers, establish joint ventures with recyclers, form consortia with competitors, vertically integrate into product recovery, or simply promote the recycling market? Should the manufacturer outsource the remanufacturing and collection process? (Toffel 2004)

7. Sustainability Performance Metrics

The common objectives when evaluating systems, processes, products, and services are mostly market share, efficiency, cost, or profit-related. We need to add/develop environmental and societal performance indicators such as wasted energy, material, and land, through emissions and carbon footprint, quality of life, and safety.

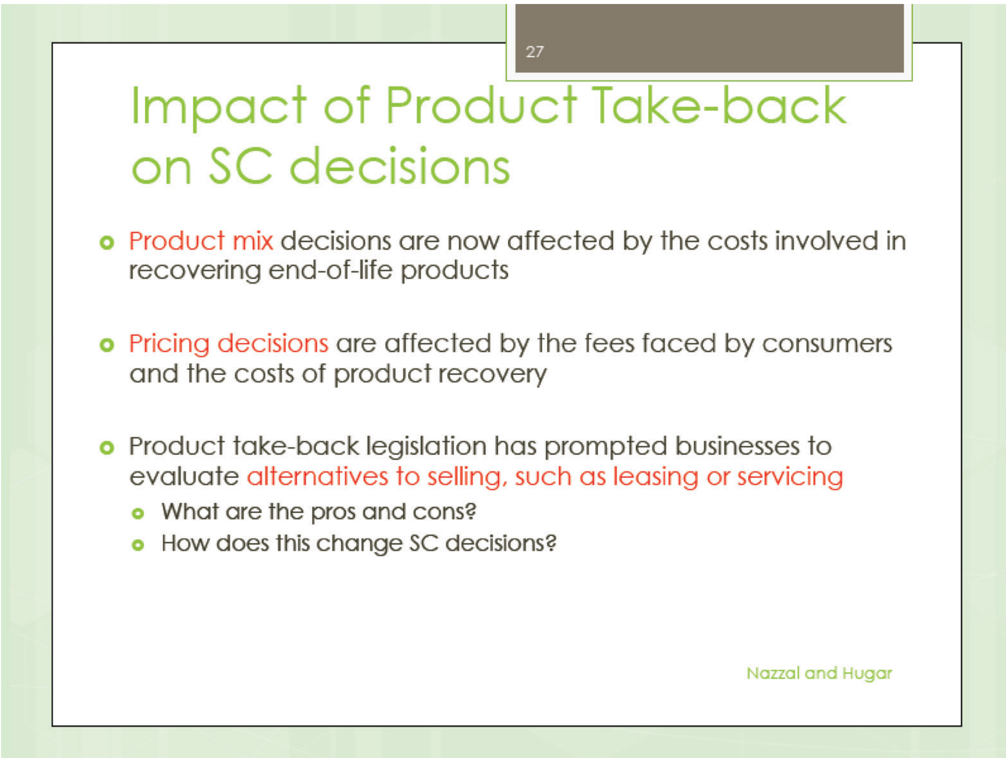
Efficiency of reverse logistics systems is another performance metric topic for industrial engineers; Fleischman (2001) describes several ways the efficiency of reverse logistics systems can be influenced by whether the manufacturer or another party manages the recovery process.

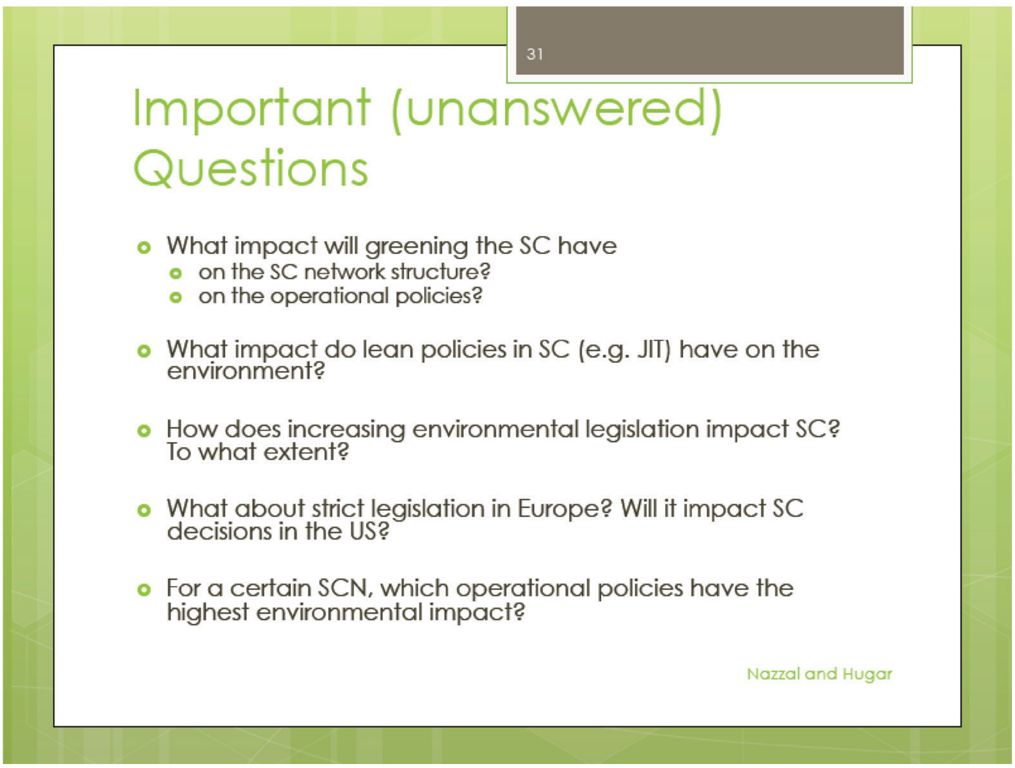
Uncertainty of reverse supply chains and humanitarian logistics networks is one important performance measure that needs to be addressed. According to Toffel (2004), remanufacturing firms report maintaining high inventories of EOL products to buffer against uncontrollable fluctuations in their supply. These non-traditional supply chains are subject to much more uncertainty than traditional supply chains for several reasons: uncertain timing and quantity of returns, the need to balance demand with returns, uncertainty in material recovered, and the problems of stochastic routings for materials for repair and remanufacturing operations and processing times.

APPENDIX C: COURSES AND PROPOSED MODULES

Course Name	Catalog Description	Area of Focus (from App. B)	Modules to be Introduced
Introduction to Industrial Engineering	An overview of the issues important to the operation of an industrial or service facility	Performance Metrics; Design for Sustainability	Social and environmental responsibility
		Design for Sustainability	Green process design and operation
Engineering Administration	Engineering organization and administration; delegation of authority and responsibility; effective use of resources; project management; R and D planning; ethics in professional practice	Performance Metrics	Social and environmental responsibility
		Environmental Management Accounting	Environmentally and energy-limited resources
Quality Engineering	Basic concepts and techniques of quality control; applications of statistics in industrial research; design of quality assurance systems; reliability engineering	Life Cycle Assessment	Serviceability of products at the consumer to extend product life
		Total Environmental Quality Management	Total Environmental Quality Management
Manufacturing Engineering	Introduction to manufacturing engineering, with emphasis on current and emerging technologies in metalworking and electronics	Design for Sustainability	Modular product design and Design for Maintainability
		Design for Sustainability; Product Recovery	Design for sustainability: Design for Recycling, Design for Simplicity, Design for Disassembly
Industrial Facilities Planning and Design	Comprehensive design of industrial production systems, including interrelationships of plant location, process design, and materials handling	GSCM	Green Facilities Design and the Carbon Footprint
		GSCM	Impact of packaging on the environment and evaluation of sustainable packaging
Operations Research	Introduction to linear, non-linear, and dynamic programming. Decision analysis, random processes, and queuing. Course covers theory through application and implementation of results	Performance Metrics; Design for Sustainability	Humanitarian applications of Operations Research (e.g. planning and responding to disease outbreaks, responding to disaster areas)
Production and Distribution Systems	Decision rules in industrial environments including Forecasting, Production Planning, Scheduling, Inventory Control, and Project Monitoring	GSCM	Green Supply Chains
		Performance Metrics; Design for Sustainability	Humanitarian Logistics

APPENDIX D: GREEN SUPPLY CHAINS – SAMPLE SLIDES





APPENDIX E: HUMANITARIAN LOGISTICS TERM PAPER ASSIGNMENT PRODUCTION & DISTRIBUTION SYSTEMS

Spring 2011

Humanitarian Logistics Assignment

Objectives:

Students develop an understanding of how logistics and inventory management can be implemented into disaster relief efforts.

Assignment Description:

Complete a two to three page paper based on recent disasters discussing areas where IE's can contribute in each of the disaster stages discussed in class.

A few examples were given in the lecture. Please use these to help get you in the mindset of developing your own thoughts and examples. Select two or three disasters and come up with one or two examples of where IE's can contribute in each of the four stages. Also discuss how each of these examples contribute to the disaster recovery effort overall.

Instructions:

1. You can work in teams of 2-3 students on this assignment.
2. We expect high quality professional papers that are free of typos and grammatical mistakes.
3. Make sure you cite all the reference you used in your research.
4. The length of the paper should be between 2-3 pages, single-spaced paragraphs, 1'' margins, using 12-point font (approved fonts: Arial, Times New Roman, Calibri, or Georgia)

APPENDIX F: PILOT COURSE DEMOGRAPHICS WHERE MODULES WERE PILOTED IN SPRING 2011

Demographics	Production and Distribution Systems	Facilities Planning and Design
Males	39 (72.2%)	45 (73.8%)
Females	15 (27.8%)	16 (26.2%)
Whites	27 (50.0%)	28 (45.9%)
Hispanic/Latino	17 (31.5%)	23 (37.7%)
Asian	5 (9.3%)	5 (8.2%)
Black/African American	4 (7.4%)	3 (4.9%)
Not specified	1 (1.9%)	2 (3.3%)
Total Enrollment	54 (100.0%)	45 (100.0%)

APPENDIX G: SURVEY USED TO EVALUATE REACTIONS TO 'ENVIRONMENTALLY AND ENERGETICALLY LIMITED RESOURCES' MODULE

Integrating Sustainability into the Industrial Engineering Curriculum Project Survey

Note: This survey is anonymous and will not affect your grade. Your professor/instructor will not have access to individual answers as the results will be reported in group format. Your feedback is very important.

Instructions: Please indicate your answer by circling the most appropriate response or answering the question completely.

1. What is your major program of study?
   a. Industrial Engineering
   b. Business Administration
   c. Mechanical Engineering
   d. Non degree seeking
   e. Please list if Other ___________________
2. What is your current status?
   a. Freshman
   b. Sophomore
   c. Junior
   d. Senior
   e. Please list if Other ___________________

The following questions are related to the learning module "Environmentally and Energetically Limited Resources".

1. Did you attend the presentation on "Environmentally and Energetically Limited Resources"?
   a. Yes
   b. No (please skip questions 4 – 15)
2. Was this your first exposure to the topic "Environmentally and Energetically Limited Resources"?
   a. Yes
   b. No

Please rate the following items by circling your choice:

Scale / Indicator	Strongly Agree	Agree	Disagree	Strongly Disagree	Not Applicable
5. I found the topic and presentation content appropriate and relevant for my major of study.	4	3	2	1	
6. The presentation developed my understanding of how Engineering solutions can be applied to achieve Environmental Sustainability	4	3	2	1	
7. The presentation developed my understanding of the need for engineering tools and methods to improve Environmental Sustainability	4	3	2	1	
8. Attending this presentation increased my knowledge about issues and challenges of sustainable systems	4	3	2	1	
9. Given the opportunity, I will be interested in applying for a senior design project that involves Environmental Sustainability	4	3	2	1	
10. The presentation left me with a sense of excitement about my career and the impact I can make to contribute to society as an Engineer.	4	3	2	1	

Please indicate your answer by circling the most appropriate response.

11. To what extent do you think you will incorporate what you learned in this module when you begin your intended career?
    a. Not at all
    b. Small extent
    c. Moderate extent
    d. Large extent
    e. N/A
12. How would you rate the QUALITY of the presentation?
    a. Needs improvement
    b. Satisfactory
    c. Above satisfactory
13. What did you really like about the Environmentally and Energetically Limited Resources lecture? Please be specific.
14. How might the Environmentally and Energetically Limited Resources module be improved to make it a richer learning experience for students in your degree program?

APPENDIX H: ASSESSMENT QUESTIONS AND METHODS

<table>
<tr><th>Measurable Outcome</th><th>Assessment Questions</th><th></th></tr>
<tr><td>1. Students will demonstrate an increase in social and environmental responsibility.</td><td>1.1. Do the students embrace sustainability in their decision-making and performance assessment?
1.2. Does the students' perception of their appreciation of the impact of engineering solutions on the environment and society improve?
1.3. How is sustainability education affecting the students' social and environmental responsibility?</td><td rowspan="2">end-of-course surveys; focus groups</td></tr>
<tr><td>2. Students will develop innovative thinking skills and improvement of leadership skills.</td><td>2.1. Are students more successful in thinking innovatively about sustainability issues within the context of the projects they work on in their courses?
2.2. What impact is the project having on students' attitude, interest, confidence and knowledge related to sustainable practices?
2.3. What kind of sustainable thinking are the students engaged in?</td></tr>
<tr><td>3. Students will be interested in embracing sustainability as a major part of their senior design projects.</td><td>3.1. Are students more successful in thinking innovatively about sustainability issues within the context of their senior design project?
3.2. Are the students being encouraged by faculty members to integrate sustainability into their projects?</td><td>direct observations over a baseline; senior design industrial mentor survey; number of projects and descriptions; anecdotal evidence
end-of-course surveys; focus groups</td></tr>
<tr><td>4. Students will be excited about their career and the impact they make to improve the environment and society as a result of their learning.</td><td>4.1. Are students more likely to see the connections to aspects of problems outside those related to the Industrial Engineering discipline, relating to sustainability?
4.2. Did the students' discussions indicate more excitement, about industrial engineering as a career because of the impact they can make on preserving the environment?</td><td>end-of-course surveys; focus group</td></tr>
<tr><td>5. Students' attitude towards the IE discipline will be improved.</td><td>5.1. Are students from other disciplines enrolling in IE courses and indicating excitement in sustainability education?
5.2. Are IE students excited about the integration of sustainability in their courses?
5.3. Are the courses providing high-quality experiences?</td><td>enrollment records with a baseline; end-of-course surveys; focus group</td></tr>
</table>

Note: As a number of these methods of assessment are appropriate over a long-term, multiyear evaluation period, not all of them were used to evaluate the successfulness of our pilot project.

APPENDIX I: STUDENT RESPONSES FROM FOCUS GROUPS

"As an industrial engineer, I think we have a lot to provide society, because we are getting the skills on how to do things more effectively and more efficiently, so we are not reinventing the wheel, we are just making the wheel a little better. If we can do this with the concept of how can we do this *and* protect the environment at the same time...Because any environmental movement that is not profitable, is not going to be picked up in the commercial world. If the company cannot do it and be profitable, the company is not going to exist."

"I thought it was interesting to see the different examples of the things that have occurred as far as what different company is doing. It shows that not every effort to be sustainable is a lost cause. Some companies are profitable while achieving the goal of being sustainable."

"As far as the greener supply chain, that was something that quite got into my head that they could have a supply chain that produces and DE manufacture as a way to help further minimize their cost for packaging and things of that nature. That was a pretty new concept. Having this knowledge may help me in the future."

"The supply chain, for the longest time has been always been raw goods, *make material, ship it, and sell it*. Now the concept is sustainable packaging. Where you are able to…bring that back and use it somehow for another product. For example, companies are realizing that the boxes that are used to ship things in can be later be used for something else. It is our culture that is changing. Instead of throwing it away, you can use it again somehow for another product.

"It was beneficial for me, in some ways, to have gone over that because I was at a job interview recently, and they work with pallets and they ship and receive, so it was a bit helpful to talk about that [sustainable packaging] at the interview [the student was interviewing for a CHEP Supply Chain Logistics Intern position]. At that point they wanted me to ask more questions about them instead of them asking questions about me so I think it was good."

"I liked how the humanitarian effort was broken down into steps, and that helped me conceptualize the different ways for how an industrial engineer could be beneficial to those processes."

"Just as far as application of methods we have learned [in other courses], like operations research, are really applicable to this [humanitarian logistics], so it was just really interesting how it could be translated…It just never really crossed my mind, how [for example] you could use that to get goods to a people in a disaster, or how you could create a web of supply stores here there and everywhere, so that if there is a disaster in one part of the country, you could still get goods to a particular area."