A Case Study of Pedagogy in an Interdisciplinary Green Engineering Course

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Abstract

This study investigates pedagogical challenges posed by interdisciplinary courses using a mixed methods case study. Current engineering education literature describes many multidisciplinary and interdisciplinary efforts – curriculum, programs, courses, and projects – but lacks concrete pedagogical strategies appropriate to such efforts.

In interdisciplinary courses, students represent a range of majors and often different academic levels. Consequently, they bring different disciplinary prior knowledge as well as different levels of understanding. This lack of common prior knowledge due to horizontal (disciplinary) and vertical (levels) integration creates unique challenges for faculty associated with both course content and instruction method.

To address these challenges, this study adopted a mixed methods approach to collect quantitative and qualitative data in an interdisciplinary Green Engineering Life Cycle Analysis course. Data included surveys, observations, and interviews. The surveys addressed students' motivation for enrollment, prior knowledge of Green Engineering, perception of the course, reflections on course content, satisfaction, and content gains. Observations of classroom and team meeting behaviors, along with interviews of students and faculty provide complementary qualitative data.

Quantitative analysis of the content knowledge data demonstrates significant gains for eight of ten concepts. Qualitative analysis shows that students also gained awareness of different perspectives from other disciplines. Qualitative analysis also identified key challenges for faculty in interdisciplinary settings: 1) structural issues related with organizing students from different disciplines with conflicting schedules and 2) disciplinary egocentrism of students through their education and training from in-major courses. The data also suggests teaching practices that have the potential to create new interdisciplinary pedagogies.

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Chapter 1: Literature Review

Within engineering education, scholars from all over the world have written about interdisciplinary curricula, programs, courses, and projects. These interdisciplinary efforts are driven by needs from industry, society, and the government, with ABET accreditation promoting continual improvement of undergraduate education. Some of these efforts focus on interdisciplinary collaboration in design, while others describe content-based interdisciplinary courses such as biomechanics and green engineering. Across all of these interdisciplinary efforts, faculty are being challenged by classrooms of students with diverse disciplinary backgrounds, leading to the question, "What pedagogical strategies are required to support interdisciplinary courses where students come from varied backgrounds?" To address this question, the unique challenges that faculty face in interdisciplinary courses first need to be identified.

1.1: Defining "Interdisciplinary"

To begin unpacking the challenges of teaching interdisciplinary courses, we first need to define "interdisciplinary." While most people use the terms "multidisciplinary" and "interdisciplinary" interchangeably, subtle differences exist between the two words. Bradbeer [1] and DeZure [2] both describe multidisciplinary learning as an *additive* process, whereas *synthesis* occurs in an interdisciplinary experience. A multidisciplinary individual is able to switch roles to conform to each discipline, while the interdisciplinary individual brings knowledge and skills from two or more disciplines together to form new insights into or about the problem or task at hand. The path to interdisciplinary learning may begin with multidisciplinary efforts, with awareness of disciplinary differences being the first step in the process, but it does not end with awareness. Interdisciplinary courses push students to develop knowledge, skills, and approaches outside of their disciplinary boundaries.

Dictionary definitions support the distinction: the Oxford English Dictionary [3] defines multidisciplinary as "[c]ombining or involving several separate academic disciplines. In contrast, the definition of interdisciplinary is "[o]f or pertaining to two or more disciplines or branches of learning; contributing to or benefiting from two or more disciplines." Within interdisciplinary efforts, both fields are advanced, creating a mutually beneficial arrangement.

Similarly, the Committee on Facilitating Interdisciplinary Research and the Committee on Science, Engineering, and Public Policy [4] defines interdisciplinary research as "a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice" (pg. 26). Again, the notion of *integrating* expertise from multiple disciplines is emphasized, with the addition of the complexity of the problem being beyond the capability of a single discipline. Figure 1 shows the differences between multidisciplinary and interdisciplinary.

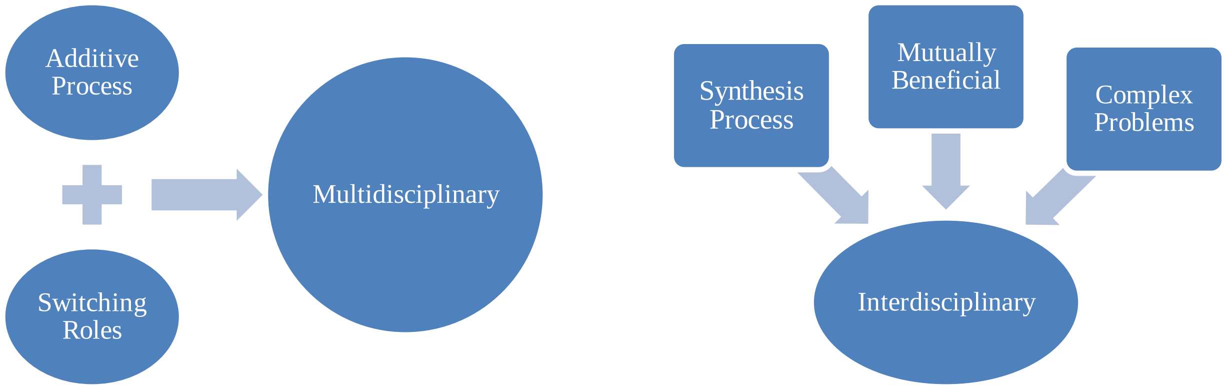

Figure 1: Visual representation of the differences between multidisciplinary and interdisciplinary

For this thesis, interdisciplinary is defined as using multiple disciplinary perspectives, knowledge sets, techniques, and skills to solve a complex problem, leading to new perspectives, knowledge sets, techniques, and/or skills that are mutually beneficial to each discipline providing to the goal of solving the problem. This definition reflects the criteria ABET sets forth not only to "work on multidisciplinary teams," but to provide the broad education students need to meet the demands of the interdisciplinary nature of industry.

1.2: The Need for Interdisciplinarity

Over the past decade, both industry pressure and socio-political events have promoted the current trend of incorporating interdisciplinary projects, courses, programs, and curricula into academia. Within engineering, these interdisciplinary efforts target issues such as security and terrorism, biotechnology, micro-electro-mechanical systems (MEMS), nanotechnology, energy, and green engineering. The broadness and complexity of these fields require, at minimum, multidisciplinary teams to function by bringing together unique skills and knowledge from different disciplines. Multidisciplinary teams have played an important role at national laboratories performing interdisciplinary research, with a primary focus on global, national, and social needs [4]. But increasingly, multidisciplinarity is not sufficient; these challenges require the integrative, synthetic approach described as interdisciplinary.

In addition, the professional skills requirements set forth by the ABET Engineering Accreditation Commission lay the foundation for training students to become interdisciplinary, such as criteria "(d) an ability to function on multidisciplinary teams" and "(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [5]. With the shift in ABET criteria to student outcomes, including both technical knowledge and professional (communication, teamwork, problem-solving) skills [5], faculty have been creating multidisciplinary teamwork opportunities and integrating knowledge about economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability issues within an engineering context [6].

Finally, the government has actively promoted interdisciplinary learning and research. The National Academy of Engineering's report, *Educating the Engineer of 2020* [7], proposes that "[e]ngineering educators should introduce interdisciplinary learning in the undergraduate curriculum" because problems in the real world are not typically discipline-specific (pg. 2, 55). These and similar reports suggest that interdisciplinary courses will be increasingly important to engineering curriculum.

1.3: Current Interdisciplinary Efforts in Engineering Curricula

In response to this need, efforts to promote interdisciplinarity have burgeoned in engineering curricula in recent years. An American Society for Engineering Education (ASEE) conference search [8] from 2003-2006 returned 624 citations on "multidisciplinary" and 834 on "interdisciplinary." A focused review of papers from the 2007 conference illustrates the scope of current efforts. Eighty-six papers were identified as addressing multidisciplinary or interdisciplinary themes out of 86 papers containing the term "interdisciplinary," 90 mentioning "multidisciplinary," and an overlap of 10 containing both terms. Table 1 shows the categorization of the conference papers according to central focus. While these conference papers came from many divisions, ASEE does have a Multidisciplinary Engineering Division. The Multidisciplinary Engineering Division held its first official meeting in June of 2003 [9].

Table 1: Categorization of interdisciplinary papers from the 2007 ASEE conference by central focus

Number of Papers	References	Central Focus	Brief Description
34	[10-43]	Courses	Descriptions of courses that had different disciplines represented in the classroom
19	[44-62]	Curriculum	Accounts of undergraduate and graduate level degree programs
15	[63-77]	Student Projects	Descriptions of multi- and interdisciplinary student projects
13	[78-90]	Program	University-wide efforts to support multi- and interdisciplinary experiences
2	[91, 92]	Assessment	Assessment of multi- and interdisciplinary teamwork
1	[93]	Symposium + Course	Description of a symposium supplementing a capstone design course
1	[94]	Research Focused	Research on the use of multimedia courseware in interdisciplinary classrooms
1	[95]	ABET Accreditation	Accreditation of multidisciplinary engineering programs and ASEE's role in program review

Table 2 shows the academic level and the interdisciplinary subject of each course described in the 2007 ASEE conference papers. This table also includes information about the inclusion of non-engineering disciplines and a description of any multi- or interdisciplinary learning objectives. These courses cover the entire range of higher education, from freshman engineering introductory courses and senior capstone designs to graduate level courses. The themes of these courses vary widely. Green engineering, security and terrorism, entrepreneurship, MEMS, and nanotechnology are all present.

Table 2: Details of the interdisciplinary courses describe

Source	Academic Level	Interdisciplinary Subject	Non-Engineering Disciplines	Sample Multi- or Interdisciplinary Learning Objectives
[10]	Undergrad	Green Engineering	No	
[11]	Senior	Design Capstone	No	"Ability to work effectively in a multidisciplinary team environment, to communicate and make tradeoffs, within and across disciplines, to meet project requirements"
[12]	Senior	Design Capstone	No	"[G]ain appreciation of interdisciplinary projects involving students from other engineering disciplines"
[13]	Senior	Entrepreneurship + Design	Yes	"[M]ultidisciplinary teams"
[14]	Undergrad	Environmental Studies Capstone	Yes	"Integrate and synthesize information from multiple disciplines" "Apply problem-solving strategies using techniques from multiple disciplines to complex problems involving both natural and human systems" "Work with others from different backgrounds to pose and evaluate resolutions to complex problems"
[15]	Senior	Design Capstone	No	
[16]	Undergrad	Bioinformatics	Yes	
[17]	Sophomore	Design	No	
[18]	Undergrad	Lean Manufacturing	Yes	"Improve communication skills for students and promote interdisciplinary collaboration in team work environment"
[19]	Senior	Design Capstone	No	
[20]	Senior and Graduate	Design Capstone	Yes	
[21]	Undergrad	Graphics	No	
[22]	Senior	Environmental Biotechnology	Yes	
[23]	Junior and Senior	Control Systems	No	"Work collaboratively across disciplines on mechatronic projects"
[24]	Graduate	Design	No	
[25]	Senior	MEMS Fabrication	No	
[26]	Undergrad	Economics	Yes	
[27]	Undergrad	MEMS Lab	No	
[28]	Senior	Green Engineering	No	
[29]	Junior	Design	Yes	Multidisciplinary teaming
[30]	Senior	Design Capstone	No	
[31]	Undergrad	Engineering Mechanics	No	
[32]	Senior and Graduate	Microfluids	Yes	
[33]	Graduate	Alternative Energy	No	

Source	Academic Level	Interdisciplinary Subject	Non-Engineering Disciplines	Sample Multi- or Interdisciplinary Learning Objectives
[34]	Undergrad	Biotechnology Labs	No	"[E]xpose all ECE students – and raise their awareness – to emerging biotechnology topics by providing them with essential and contemporary BME knowledge" "[T]o enhance their comprehension of core ECE concepts by applying such concepts to multidisciplinary real world problems in medicine"
[35]	Undergrad	Robotics	No	
[36]	Sophomore	Design	No	
[37]	Undergrad	Professional Development	No	
[38]	Senior	Design Capstone, Innovation	Yes	"Working in a multi-disciplinary team gave rise to different ideas and approaches to problems from people with different backgrounds" "Realising and appreciating diverse skills from other team members"
[39]	Undergrad	Engineering Lab	No	
[40]	Undergrad	Community Development	Yes	
[41]	Freshman	General Engineering	No	
[42]	Senior	Design Capstone	No	"Ability to work effectively in a multidisciplinary team environment, to communicate and make tradeoffs, within and across disciplines, to meet project requirements"
[43]	Senior or Graduate	Security and Bioterrorism	Yes	

Importantly, however, these papers do not focus on the challenges faculty encounter; rather, they highlight the multi- and interdisciplinary nature of the subject. Learning objectives from these courses, when defined, focus on the awareness of the need for disciplinary expertise outside of the student's discipline.

1.4: Green Engineering

A number of the interdisciplinary efforts described at ASEE and similar conferences address "Green Engineering." Green Engineering is an interdisciplinary field, drawing students from the traditional disciplines of engineering and uniting them around issues of sustainability. The EPA defines Green Engineering as: "the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment" [96].

Green Engineering is an ideal site to study interdisciplinary teaching and learning due to its complexity in drawing together multiple disciplines and its focus on performance, economics, sustainability, human health, and environmental impacts. With the current societal focus on environment and global sustainability, faculty members have a new framework to broaden students' perspective of engineering. The challenges of sustainability are inherent to all engineering disciplines, with the generation and use of energy and resources as a common thread. The depletion of non-renewable fossil fuels and the resulting pollution has adversely impacted the environment; this strain on ecosystems threatens both biodiversity and human well-being [97]. As a component of sustainability, Green Engineering provides an interdisciplinary experience to equip students with the knowledge and skills to meet these challenges. Green Engineering also incorporates non-engineering subjects such as economics and ethics through concepts and techniques such as economic valuation and Disability Adjusted Life Years (DALY) or Quality Adjusted Life Years (QALY).

While Green Engineering provides students with new content knowledge relating to the environment, it also draws on disciplinary knowledge. Using the four phases of the life cycle (extraction, manufacturing, use, and end of life) as an example, different disciplines typically focus on one phase without awareness of the other phases. For example, a traditional mechanical engineer may design a product with only the use phase in mind; an industrial and systems engineer may examine a manufacturing process to minimize production time and/or waste; a mining engineer may focus on extraction methods of raw materials to create more efficient and safe extraction processes. Thus, mechanical engineers designing a "green" vehicle may focus on the engine efficiencies or fuel economies of different potential solutions (gas-electric hybrid, bio-diesel, plug-in hybrids, electric, hydrogen-powered) without considering the environmental impacts associated with obtaining materials and using energy associated with creating fuels for these design solutions. Yet the consideration of the whole life cycle is a fundamental concept of Green Engineering, and its success depends upon interdisciplinary integration of expertise.

1.5: Challenges of Interdisciplinary Collaboration and Learning

Despite the increase in interdisciplinary efforts in engineering courses, the literature to date provides little direct discussion of the pedagogy associated with these learning environments.

1.5.1: Pedagogy

The term "pedagogy" refers to the "art, occupation, or practice of teaching" or "the theory or principles of education; a method of teaching based on such a theory" [3]. Ormrod [98] states the basic principle behind any instructional method, or pedagogy, is "how well it promotes effective storage processes" for knowledge (pg. 222). From constructivism, the theory that humans construct meaning from their experiences (pg. 163), one such method of storing knowledge is meaningful learning; meaningful learning is "storing [knowledge] in long-term memory in association with similar, related pieces of information" (pg. 203). In other words, when students engage in meaningful learning, they connect new knowledge with prior knowledge. Bransford et al. [99] build upon the concept of meaningful learning when they describe a learner-centered environment. In learner-centered environments, professors acknowledge the "knowledge, skills, attitudes, and beliefs that learners bring to the educational setting" (pg. 133). Learner-centered environments and meaningful learning have led engineering educators, such as Smith et al. [100], to adopting "pedagogies of engagement," or active learning pedagogies.

In favor of critical and learner-centered pedagogies, Freire, in *Pedagogy of the Oppressed* [101], criticizes the narrative or lecture-style of teacher-centered instruction. In what he calls "banking concept of education," the instructor possesses the knowledge, while students "receive, memorize, and repeat" without inquiry into or application of that knowledge (pg. 72-73). The ontological implication associated with the banking concept is that reality becomes "motionless, static, compartmentalized, and predictable" (pg. 71). Epistemologically, knowledge is gained though memorization from an authority source; learners automatically accept knowledge without any critical evaluation. In both ontological and epistemological terms, this model works against interdisciplinary integration.

Effective pedagogies will also motivate the students in the classroom, a critical issue for faculty asking students to step out of their disciplinary comfort zones. Motivation can either come from external sources or within the individual. External motivation, known as extrinsic motivation, stems from the desire to acquire desirable, or avoid undesirable, consequences. For college students, a source of extrinsic motivation to complete a degree is the appeal of a high paying career. On the other hand, intrinsic motivation is when an "an individual finds the task enjoyable or worthwhile in and of itself" [98] (pg. 454). An example of intrinsic motivation is the graduate student that pursues courses in psychology because he finds the subject fascinating and wants to become a future professor. While motivating every student to an intrinsic level may be the "optimal" goal, a motive may have both extrinsic and intrinsic attachments for the individual [98] (pg. 455). A student's emphasis on grades may be extrinsic in wanting to pass a course while also intrinsic in gaining a higher level of self-efficacy towards the subject.

While learning and motivation occur on the personal level, students from the same discipline may share similar learning strategies and motivations due to their similar backgrounds. The lack of such shared strategies and motives poses an important challenge to interdisciplinary faculty.

1.5.2: Challenges in the Interdisciplinary Classroom

With the influx of faculty developing and teaching interdisciplinary courses, these and similar challenges unique to these courses are emerging. To improve student learning and satisfaction in interdisciplinary courses, faculty need to be aware of and prepared for these difficulties. This thesis identifies challenges associated with an interdisciplinary green engineering course, emphasizing the unique difficulties associated with the interdisciplinary nature of the course.

Within a discipline, students share a general body of knowledge gained from their education within the institution. When these students come together as seniors to work on a capstone design, fewer concepts and knowledge gaps need to be reconciled as the project moves forward. For example, students working on autonomous vehicles come from various disciplines, including but not limited to mechanical engineering, electrical engineering, and computer science/engineering. Each discipline brings specific theories and applications to the project. Mechanical engineers bring concepts of drag, lift, and strength of materials to the project; electrical engineers contribute knowledge of sending, receiving, and processing signals; and computer science engineers bring programming skills and knowledge of visual detection. On such a project, students from different disciplines mostly likely will take a "divide and conquer" approach rather than an integrative one [102]. Students with particular expertise will conduct tasks that align with their knowledge and skills. Creating an interdisciplinary collaboration is much harder because it involves merging information from each discipline, giving each individual a common background while still incorporating their expertise.

Some scholars have begun to address this problem. O'Brien, in a 2003 study of a multidisciplinary capstone design course at the Master's level, states three broad challenges associated with interdisciplinary collaboration: 1) "lack of knowledge about the information needs of others" 2) "lack of integrative knowledge and abilities within and across disciplines" and 3) "cultural expectations may vary with individuals and discipline" [102]. While these challenges were observed in design teams, they can be applied to instructional settings by viewing the instructor as a team leader and the students as members of the group.

Similarly from his review of literature in 1999, Bradbeer lists difficulties associated with interdisciplinary learning as stemming from difference in epistemologies, discourses, and traditions of teaching and learning between disciplines and individual differences associated with faculty conceptions of instruction and student approaches to and styles of learning [1]. A first step to overcoming these challenges is awareness of differences between disciplines. Even with this meta-knowledge, faculty members in interdisciplinary courses need to communicate effectively to students of all disciplinary backgrounds within the classroom and integrate knowledge from the disciplines.

While the work of O'Brien and Bradbeer represents an important staring point, many gaps still remain in identifying concrete steps faculty can take when leading interdisciplinary courses.

1.6: Disciplinary Egocentrism

One theoretical framework useful for understanding the kinds of pedagogical challenges faced by instructors in interdisciplinary settings is the concept of "egocentrism" as defined by Piaget [98]. Commonly, egocentrism is used to describe someone that is self-centered, but in Piaget's theory of cognitive development, he uses the word to describe individuals lacking the ability to think beyond their own perspective. In children, he theorizes that they do not have the cognitive development to think from another perspective (pg. 314). Within adults, this egocentrism is "adolescent idealism," defined as "the inability to separate logical abstractions from others' perspectives and practical considerations" (pg. 318). These individuals will come up with a "solution" to a problem (usually large scale) from their limited perspective of the problem and world.

A similar problem can plague disciplinary experts. Disciplines are defined through the development of paradigm, by reaching a consensus of among scholars about the knowledge, methods, and skills that will advance a the field [103]. Under the current methods of disciplinary formation, students must be taught the epistemology and ontology of the discipline by professors who were taught the same knowledge, methods, and skills. This narrow perspective, or "disciplinary egocentrism," becomes a key source of problems when working on interdisciplinary problems. To date, however, engineering education researchers have few, if any, systematic accounts of disciplinary egocentrism as it is manifested in interdisciplinary settings. As a result, little is known about what educators can do to overcome this barrier.

1.7: Conclusion

The literature from conferences and journals show many interdisciplinary efforts emerging in academia, but lacks discussion on the challenges of teaching interdisciplinary courses and the skills faculty need to overcome these challenges. Critical gaps include:

- clear pedagogical strategies used in teaching an interdisciplinary course;
- learning objectives clearly marking multi-/interdisciplinary skills as course outcomes;
- assessments for interdisciplinarity;
- interdisciplinary courses for early curriculum (freshman, sophomore);
- horizontal integration with non-engineering disciplines; and
- vertical integration of students from all academic levels.

Though all of the issues raised are critical, this thesis focuses on the first of these gaps – pedagogies for interdisciplinary classrooms – as a starting point. It addresses the question, "What pedagogical strategies are required to support interdisciplinary courses where students come from varied backgrounds?" In order to develop these strategies and prepare faculty to teach interdisciplinary courses, the unique challenges of interdisciplinary courses first need to be systematically articulated. With this thesis, the researcher investigates the unique challenges from an interdisciplinary green engineering course.

Chapter 2: Methodology

2.1: Overview

To investigate the pedagogical challenges faced by instructors in interdisciplinary courses, this thesis presents a case study of an interdisciplinary course in Green Engineering offered once a year. The case study includes quantitative and qualitative survey data, observations, and interviews. In Year 1, the course instructor, without input from the researcher, piloted a pre- and post-course survey addressing both technical content and class satisfaction; this data serves as a baseline for redesigning the survey. For Year 2, this set of surveys was redesigned by the researcher, and observations of the course and student team meetings and interviews with the students and instructor were added.

Data from the redesigned pre- and post-course surveys was collected to assess gains in students' cognitive knowledge of Green Engineering concepts, as well as students' initial motivation and final perception of the course. Additional surveys, used as formative assessments, helped evaluate students' perceptions about the class and encouraged students to reflect on the material presented in lecture. Finally, the researcher also collected complementary qualitative data from classroom and team meeting observations and interviews with students and the instructor. Throughout the Year 2 course, the researcher functioned as a participant observer in the classroom, with the degree of participation in the middle of the continuum between full participant and complete spectator [104] (pg. 265). The researcher did learn the topics of Green Engineering and environmental life cycle analysis, but did not answer questions in class or complete any homework or quizzes. All Year 2 data sources were collected, compiled, and analyzed by the researcher.

For this mixed methods research, the data was analyzed with quantitative and qualitative methods appropriate for the type of data collected [105]. Cognitive content questions were scored and analyzed using a one-way ANOVA test for comparisons of background knowledge from the pre-course survey, and a paired t-test for a pre- and post-course comparison to gage students' gains in content knowledge; Likert-scale ratings were tallied and described by the mode of responses. The qualitative data from open-ended survey questions, classroom observations, and the interviews were open-coded and analyzed for themes emerging from the data relating to pedagogy in interdisciplinary courses.

For this study, approved by the University's Institutional Review Board (IRB # 06-554), data was collected anonymously to remove influence on grades and to promote unbiased answers. In order to track individual's responses on the pre-course, formative, and post-course surveys, the researcher asked the students to create a four digit identification code at the beginning of the study. These self-selected identification codes never were linked to students' names.

2.2: Using a Case Study Approach

According to Yin [106], three conditions help direct a researcher to using a case study: 1) the nature of the research question is typically explanatory, exploratory, or descriptive, typically structured "how" or "why"; 2) the investigator lacks methods to control the site and participants; and 3) the phenomenon being studied is contemporary and the context is real-life (pg. 1).

Because, as the literature review demonstrated, very little is currently known about pedagogies appropriate for interdisciplinary courses, this exploratory study adopted a case study approach to describe the challenges from a single course and pave the way for future work. More specifically, the course addresses the conditions of case study research as indicated in Table 3.

Table 3: Research setting compared to the conditions listed by Yin [106]

Conditions	Research Setting
Nature of the research question	While the ultimate goal is to identify interdisciplinary pedagogical strategies, the research question addressed is an exploratory question to determine the challenges for faculty teaching an interdisciplinary course.
Ability of control	The researcher had no control over enrollment and outside factors that could influence students' performance and reactions to the course.
Contemporary phenomenon	Both Green Engineering and interdisciplinary collaboration are contemporary in both research and industry.
Real-life context	Students in an interdisciplinary course provides a situated context in which students are learning about Green Engineering among students of different disciplinary backgrounds and later, when they enter the workforce, will be practicing among colleagues of difference disciplines and functions.

A major strength of a case study is the ability to collect data from a variety of sources for triangulation [106]. Mathison defines triangulation as "[using] multiple methods, data sources, and researchers to enhance the validity of research findings" [107]. Mathison also discusses the possible outcomes of triangulation: convergence, inconsistency, and contradiction; she reasons that researchers can explain and theorize about the researched phenomenon with any of these triangulation results. For example, in a study exploring how pedagogy affects students' performance and attitude, surveys assessing knowledge and perceptions can be triangulated with additional data of observations of students reacting to the pedagogy and follow-up interviews. In this study, data triangulation provides multiple participant perspectives to aid the researcher in identifying the challenges instructors face when teaching interdisciplinary courses.

2.3: Research Setting: The Green Engineering Program and LCA Course

2.3.1: Green Engineering Program

This thesis focuses on a case study of a single Green Engineering course at a large state research university. The Green Engineering program began with a committee in 1993 focused on identifying courses with environmental elements within the university curriculum. In 1998, students were able to enroll in courses for a Green Engineering concentration; this concentration was approved as a Green Engineering minor starting with 2009 graduates. Students pursuing the minor are required to take two courses from each of three areas: core courses, engineering electives, and interdisciplinary electives. The two required courses are 1) Introduction to Green Engineering and 2) Environmental Life Cycle Analysis and Materials Selection, with the latter being the focus of this study. Engineering elective courses are those offered within the various departments within the college of engineering that have at least 25% of the content focusing on environmental impacts of engineering decisions; an approved list of these courses is available on the Green Engineering Program's website. The approved interdisciplinary courses, also listed on the website, are offered from departments outside of the college of engineering; these courses have at least 25% of the content focusing on technical, social, political, or economic consequences of environmental issues. While the Green Engineering minor is available to all students at the university, a number of the engineering electives have pre-requisites, making it difficult for non-engineering students to enroll. Thus, the engineering electives typically include students from traditional engineering disciplines.

2.3.2: Environmental Life Cycle Analysis and Materials Selection Course

In particular, this study focuses on Environmental Life Cycle Analysis and Materials Selection. This course is typically taken by juniors and seniors from the various engineering departments at the university and taught once a year by the same faculty member. In this case, the instructor has an academic background in materials science and chemical engineering and industry experience in Design for Environment; while still in industry, he taught himself the methods of Life Cycle Analysis and began attending conferences.

The course introduces the concepts of life cycle and Life Cycle Analysis (LCA), preparing students to evaluate environmental impacts of engineering decisions by using LCA. LCA is a quantifiable analysis used by designers to minimize the environmental impacts of products, processes, and systems. The course also highlights the significance of decisions in the design and material selection phases, and how these decisions can drastically alter environmental impacts.

The content of the course begins with an overview of LCA and environmental impacts before describing the specific steps of LCA: extraction, manufacturing, use, and end-of-life. Additional lectures cover the concepts of LCA goal and scope, inventory analysis, input-output analysis, impact assessment, weighting, streamlined LCA, product design, and recycling. The syllabus, including the learning objectives, is located in Appendix A.

In addition to conceptual knowledge of LCA, students also learn to use professional LCA software; the software used for this class is SimaPro [108], which includes established data for common materials and processes as well as different methodological approaches to impact assessment. Since a group project requires a complete LCA using SimaPro, the manual for this software is assigned as supplemental reading, and several tutorials are required homework.

2.3.3: Participants

Figure 2 represents the students that completed the course for both the pilot study, Year 1, and the semester of data collection, Year 2. For the pilot study in Year 1, 30 students completed a pre-course survey, while 29 completed the post-course survey. The total enrollment for the course in Year 1 was 33 students. The students represented five engineering disciplines: industrial and systems (ISE), materials science (MSE), mechanical (ME), chemical (ChE), and civil and environmental (CEE).

The demographics for Year 2 vary slightly from Year 1; 30 students completed Environmental Life Cycle Analysis and Materials Selection. The majority of the students were juniors and seniors in engineering disciplines, with one student at the freshman level majoring in industrial design (IDS), offered through the college of architecture and urban studies. The engineering students came from four disciplines: industrial and systems (ISE), materials science (MSE), mechanical (ME), and civil and environmental (CEE). Nine of the Year 2 students indicated they completed Introduction to Green Engineering prior to enrolling in Environmental Life Cycle Analysis and Materials Selection.

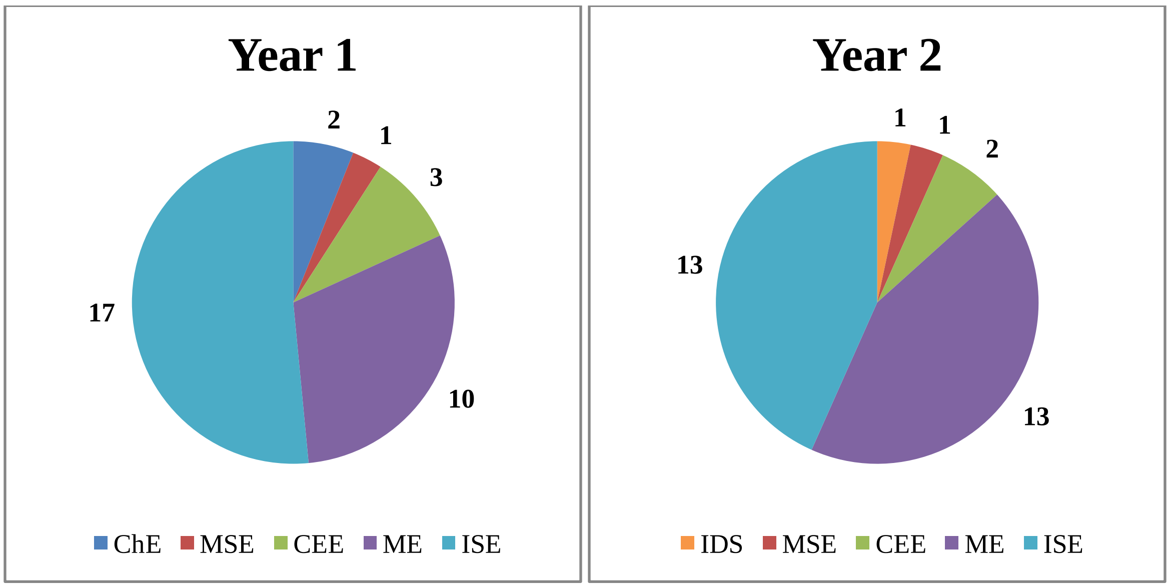

Figure 2: Visual representation of students from each discipline for Year 1 and Year 2

2.3.4: Teaching Methods

The instructor of the course was a new, non-tenure track faculty member with approximately two years of teaching experience at the university; prior to this academic appointment, the instructor had taught several modules within industry. The instructor reported that Year 1 was a largely lecture-based course using Microsoft PowerPoint presentations, due to his comfort from having given multiple presentations in industry. For Year 2, the instructor chose to reduce the number of PowerPoint slides and begin engaging the students in discussions. The lecture slides contained Green Engineering and LCA concepts and techniques, and the instructor posted these slides to the primary course website using the Blackboard course management software.

To supplement lecture in Year 2, students were assigned readings from multiple sources, including book chapters, the software manual, and articles. The instructor did not choose a primary textbook since current textbooks covering LCA either focus one chapter narrowly on how LCA is used within a specific discipline or are complex studies of LCA without applications to engineering. The instructor chose the manual from the SimaPro software because it included a general LCA overview as well as tutorials for operating the software. Additional articles from technical journals contained case studies of LCA being used in industry to show students how they may benefit from having LCA knowledge and skills. A list of the assigned readings is included in Appendix B.

Throughout the semester in Year 2, students were given homework assignments, quizzes, and a group project. Several homework assignments, focusing on the life cycle phases, built upon each other and culminated in a "factsheet" about a product made from a specific material. All of the assignments related to the themes and concepts currently being taught in the lecture. The instructor created ten homework assignments (see Appendices C-L for the actual assignments); an overview of the assignment topics and types is shown in Table 4.

Table 4: Summary of the homework assignments

Assignment Number (Appendix)	Topic	Assignment Type
1 (Appendix C)	• "Green" products memo	• Personal reflection
2 (Appendix D)	• Extraction phase memo	• Research skills • Writing skills
3 (Appendix E)	• Manufacturing phase memo	• Research skills • Writing skills
4 (Appendix F)	• Databases, software, functional units	• Performance
5 (Appendix G)	• Functional unit, scope, assumptions, input-output models	• Critical thinking skills
6 (Appendix H)	• Use and end-of-life phases memo	• Research skills • Writing skills
7 (Appendix I)	• Weighting	• Personal reflection
8 (Appendix J)	• Evaluating LCAs	• Critical thinking skills
9 (Appendix K)	• Creating a "factsheet" • Evaluating factsheets	• Research skills • Writing skills • Critical thinking skills
10 (Appendix L)	• Interdisciplinary teamwork experience	• Personal reflection

In addition to the homework, quizzes were given in Year 2 to test students on Green Engineering and LCA specific concepts (see Appendices M, N, O, P, and Q for quizzes). The instructor chose not to announce the quiz dates to promote attendance and to encourage students to pay attention in class and review the material at home.

Shortly before midterm break of Year 2, the students were assigned to teams for the group project using a modified randomized approach. All students in attendance on the specified day randomly drew a number between 1 and 6 from a small box; as a first pass, all students with the same number were assigned to the same team. The instructor then rearranged teams so that none had more then 3 students from either of the highly represented disciplines (ME and ISE). Table 5 shows the disciplinary composition of the student teams. The teams were given time in the following class meeting to select a product for a Life Cycle

Analysis. The final deliverable for this project was a report containing several key pieces of information. A more detailed explanation of the project is included in Appendix R, and Appendix S contains an assignment designed to prepare students for the initial meeting with the instructor to discuss the scope of the team project and responsibilities of each team member.

Table 5: Disciplines of team members grouped by arbitrary team number

1	2	3	4	5	6
ME	ISE	ME	ME	ISE	ME
MSE	ME	ISE	ISE	ISE	ME
ME	CEE	ISE	ME	ME	ISE
ISE	ISE	CEE	IDS	ME	ISE
ME	ME	ME	#	ISE	ISE
ISE					

Note: # indicates the student dropped the course after team assignment

2.4: Data Collection

For this study, a set of pre- and post-course surveys were developed, initially by the instructor, and implemented in Year 1 as pilot data. This data was then analyzed by the researcher to identify key issues and improve the surveys for Year 2 and determine other data collection methods. For Year 2, the researcher decided to include two additional surveys, observations, and interviews to triangulate the pre- and post-course survey data. In addition to elaborations of the data collection instruments and methods, details on the administration of the surveys are included in this section.

2.4.1: Pilot Survey and Survey Design

The instructor created a pair of surveys as a means of assessing students' prior knowledge of Green Engineering concepts, specifically relating to LCA, and their gains in conceptual knowledge from participating in the course. These cognitive questions were worded as short answer questions and directly assessed a number of the course learning objectives. Additionally, the instructor was interested in student motivation for enrolling in the course and student perceptions at the end of the semester. To investigate student motivation and perception, the instructor included an open-ended pre-course survey question asking students their motivation for enrolling in the course, while the post-course survey incorporated multiple affective questions associated with student perceptions; the affective questions were Likert rating scales with an optional open-ended response. The instructor administered these surveys to the students of Year 1. The pilot pre- and post-course surveys from Year 1 are included in Appendix T and Appendix U.

Prior to Year 2, the researcher analyzed and subsequently redesigned the pilot surveys. The surveys were modified to clarify vague wording, provide answer prompts, and improve the rating scales while preserving the ability to compare across course offerings. These modifications were implemented to reduce the time required for students to complete the surveys, decrease the ambiguity of the questions and types of responses for the students, and increase the ease of coding for the researcher. For example, the instructor initially asked students to "*Explain in a few sentences why you are taking this class*," an open-ended question. The researcher found categories in the responses by using an open-coding method [104]; these categories then became the checklist on the Year 2 pre-course survey, with an "other" option for students to write in additional motivating factors not found during the pilot study. Another modification to the surveys was with the Likert-rating scales. Initially the instructor included numeric (1 to 10), ten-point scales for students to rank how they felt about the particular aspect being addressed in the question. The researcher replaced the numeric scales with carefully worded verbal, six-point scales to help students determine the categorical rankings. The instructor and researcher also devised a method of anonymously linking pre- and post-course surveys to compare an individual student's pre- and post-course answers, which was particularly important given the small sample. This coding method was a student self-selected 4-digit number, preceded by a "G" if the student completed Introduction to Green Engineering. The analysis and redesign of these surveys resulted in an ASEE conference paper, which includes a more in-depth analysis of the pilot survey data [10].

The data from the pilot surveys, although not designed by the researcher, yielded valuable insights about student motivation, satisfaction, and learning that helped shape Year 2 data collection. From the pre-course survey, the researcher noted the wide variety of reasons motivating students to enroll in the course and identified the potential to collect more data to further analyze prior knowledge. After analyzing the data from the post-course survey, the researched noticed a lack of questions pertaining to the team project, which corresponded to a large portion of the overall course grading scheme. Recurring themes in student responses on the post-course survey were concerns about learning the software, suggestions to engage the students in discussion and other activities, and comparisons/contrasts of Green Engineer to other engineering disciplines. The researcher decided to attend class periods to observe students' behaviors during lecture and discussion. To assess students' participation and satisfaction of working on the team project, additional questions were added to the post-course survey, and the researcher also decided to observe team meetings. Student comments comparing and contrasts of Green Engineering to the other engineering disciplines eventually led to asking students to include the abbreviation for their major to their self-selected identification code.

2.4.2: Year 2 Data Collection

After completion of the pilot study and survey redesign, additional data was collected to investigate the research question. The data collection included both quantitative (quant.) and qualitative (qual.) data and methods.

- **Pre-Course Survey (quant.):** This survey, included in Appendix V, quantitatively assessed students' motivation for taking the course, perceptions regarding the importance of environmental design constraints, and prior knowledge of LCA concepts.
- **Formative Surveys (quant. and qual.):** Additional survey data was collected from two surveys used as formative assessments, modeled after "minute papers" [109, 110]. These surveys included affective Likert-scale ratings and reflective questions addressing content, pedagogy, and curriculum. These surveys are included as Appendix W and Appendix X.
- **Post-Course Survey (quant. and qual.):** This survey, included in Appendix Y, included several affective questions preceding cognitive content questions; the cognitive questions were identically reproduced from the pre-course survey. The addition of the affective questions altered the numbering, but not the order, of the content questions. The affective questions predominantly

contained Likert-scale ratings with an optional open-ended response, but several completely open-ended response questions were also included on the survey.

- **Classroom Observations (qual.):** Observation data from the course was collected to further investigate the pedagogy used in the course and the students' reactions to that pedagogy.
- **Team Observations (qual.):** As part of observing the course, the researcher also observed the student teams working on the project. The teams were given several periods to meet and discuss the project. During these classes, teams met with the instructor to discuss the chosen product, define the project goal and scope, and clarify any questions and concerns. One group volunteered to be observed outside of class time, but they never met outside of class time.
- **Interviews (qual.)**: Semi-structured interviews were held with both the faculty instructor and a subset of students from the course. The instructor was interviewed to gain insight into the underlying decisions and thought processes about pedagogy used in teaching the course. Student interviews probed student's understanding of LCA and the alignment of LCA with his/her major, motivation for enrollment in and promotion of the course, and reflection on classroom experiences. Because of unexpected events, these interviews occurred in the semester after the course ended, after a seven month interval, rather than at the end of the course as originally planned.

Table 6 summarizes the data collection instruments and administration for both Year 1 and Year 2.

Table 6: Summary of the data collection instruments

Instrument	Administration	Response Rate	Goal
Pre-Course Pilot Survey	Year 1 students: first class period	90.9%	• Trial of the pre-course survey • Data used to improve the instrument
Post-Course Pilot Survey	Year 1 students: end of semester	87.9%	• Trial of the post-course survey • Data used to improve the instrument • Validation for instructor's changes to the course
Pre-Course Survey	Year 2 students: first class period	93.3%	• Assess motivation and prior knowledge
Minute Survey #1	Year 2 students: week 3	76.6%	• Student feedback of the classroom experience for immediate improvement • Provided students a chance to reflect on understanding of content knowledge
Minute Survey #2	Year 2 students: week 8	80%	• Student feedback of the classroom experience for immediate improvement • Provided students a chance to reflect on understanding of content knowledge
Post-Course Survey	Year 2 students: end of semester	63.3%	• Assess gains in content knowledge • Student reflection on classroom experiences • Provide rational for future course modifications
Classroom Observations	Year 2: entire semester	N/A	• Insight into instructor-student interactions
Team Meeting Observations	Year 2: entire semester	N/A	• Exploration of interactions between students of different disciplinary backgrounds
Student Interviews	Year 2 students: next semester	N/A	• Recollection of content knowledge • Alignment with or deviation from students' major • Reflection on classroom experiences

Instrument	Administration	Response Rate	Goal
Instructor Interviews	Year 2 instructor: next semester	N/A	• Gain information of instructor's background and the Green Engineering program • Insights into instructor's pedagogical strategy • Instructor's reflection on classroom experience

Year 1, n=33
Year 2, n=30

2.4.3: Survey Administration

The pre-course survey was administered on the first day of class for the semester. During the third week of the semester, all students in attendance completed the first formative survey. Over the following month, the instructor made multiple efforts to engage the students in class discussion; then students completed the second formative survey. Near the end of the semester, the instructor sent an electronic copy of the post-course survey for the students to complete and return, with the options of returning a completed electronic copy or printing and submitting a hardcopy. As the semester progressed, students were asked to include the abbreviation for their major to help with discovering/identifying any potential difference between disciplines and other interdisciplinary factors.

2.4.4: Trimmed Data Set

Initially, 28 students completed the pre-course survey, while only 19 finished the post-course survey. Of the 19 post-course surveys, 3 did not have a code written on them and 1 survey did not have a match from the pre-course surveys, thus leaving 15 useable pairs of surveys in the trimmed data set. Of these 15 surveys, 10 students identified their major through their code: 4 ME, 4 ISE, and 2 CEE. Additionally, 6 students indentified they had completed the Introduction to Green Engineering course by including a 'G' with their code. One student from each discipline, ME, ISE, and CEE, indicated they had completed the Introduction to Green Engineering course; see Table 7 for the demographic data pertaining to students' major and Green Engineering background.

Table 7: Trimmed data set respondents grouped by major and completion of Introduction to Green Engineering

	Major				
Introduction To Green Engineering	**Unknown**	**CEE**	**ISE**	**ME**	**Totals**
Yes	2	1	2	1	6
No	3	1	2	3	9
Totals	5	2	4	4	15

2.5: Data Analysis

For this mixed methods research study, quantitative and qualitative data were collected simultaneously, but were analyzed according to data type [105]. Quantitative analyses include ANOVA, paired-t tests, and descriptive statistics. Qualitative data from the surveys were open-coded with themes relating to content, course materials, pedagogy, motivation, perspective, and discipline/major emerging from the data. The coding structure from the survey analysis was then used to code the observation and interview data.

2.5.1: Quantitative Analysis Methods

A one-way ANOVA analysis was performed on the cognitive questions from the pre-course survey to determine differences between prior knowledge from the Intro course or students' discipline.

For the pre- and post-course comparison, a paired t-test was performed since the data was naturally linked [111] through the student self-selected identity code. For this portion of the analysis, a trimmed dataset from the pre- and post-course surveys was used to perform a paired t-test. This data set was restricted to completed pre- and post-course surveys linked by a student self-selected identification code.

The post-course survey also included quantitative data of the affective questions. Data from the affective questions were analyzed from the complete data set of survey respondents. Since the affective questions were written as Likert-scale ratings, trends in the data were analyzed by the mode of responses [112].

2.5.2: Qualitative Analysis Methods

The affective questions on the post-course survey also included an optional open-response section for students to elaborate on their rating. The open-response data were open-coded to find emerging themes, adhering to qualitative methods [113]. For each question, responses were analyzed by complete thought, expressed either as phrases or complete sentences. These pieces of data were then examined for a central theme; then the themes from each piece of data were compared, and similar themes were grouped into categories. Where applicable, the themes and categories were repeated in coding the responses to other questions.

The themes from the open-coding of the survey data were then used to code the observation and interview data. The results from coding the observation and interview data were then compared with the survey data as a method of triangulation.

Chapter 3: Results

This chapter presents the results of the mixed methods data collection and analysis in three sections. The first section contains the findings relevant to Green Engineering content knowledge. Challenges general to teaching are presented in the second section. The final section presents the unique challenges faculty face in interdisciplinary classrooms.

3.1: Green Engineering Content Knowledge

Several data sources provided details about students' content knowledge, as described in the flowing sections.

3.1.1: Prior Knowledge

The cognitive questions from the pre-course survey assess students' prior knowledge of Green Engineering and LCA concepts. Figure 3 shows the normalized aggregate score for each cognitive question. As a whole, the class seems to have some content knowledge of Green Engineering from other courses or coverage in the media, but their prior knowledge is not sufficient to "pass" if these questions were the final examination. Certain areas, such as the four steps of LCA and environmental impact categories, apparently are not introduced in other courses or expressed in media.

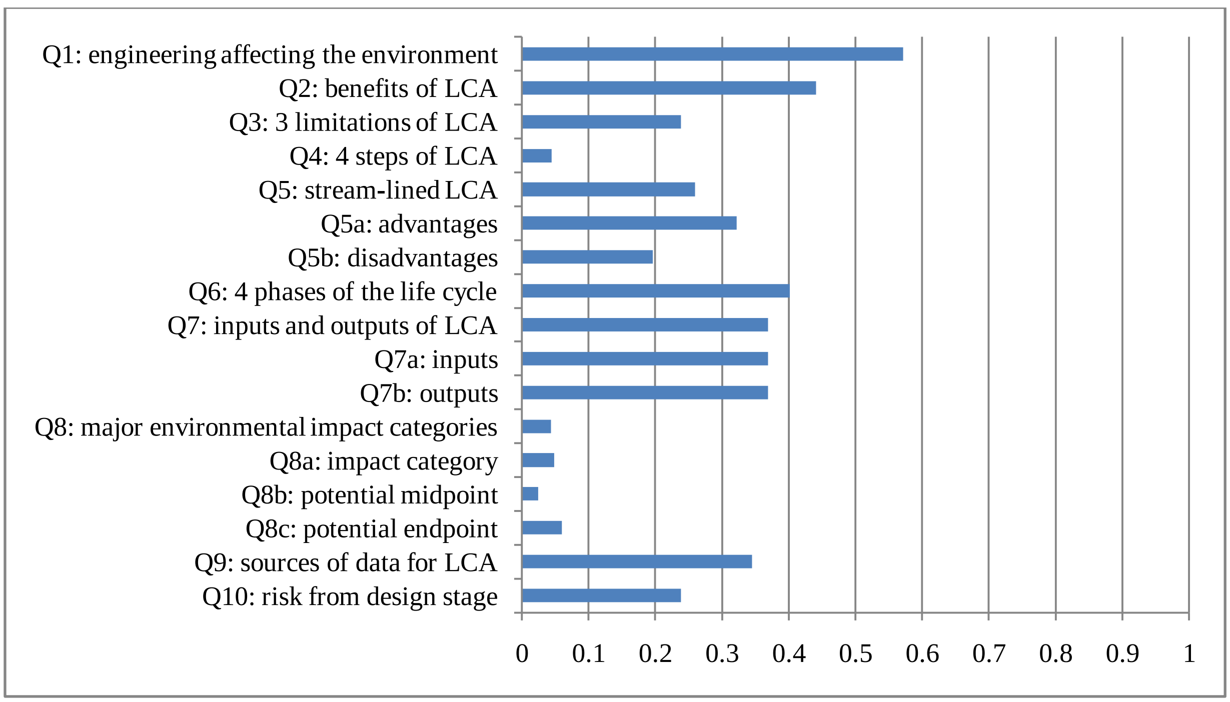

Figure 3: Normalized aggregate scores for each cognitive question on the pre-course survey

For the cognitive questions on the pre-course survey, one-way ANOVA tests were performed to highlight potential differences in the students' scores due to major and completion of Introduction to Green Engineering. Table 8 displays the numbers of students from each major by completion of Introduction to Green Engineering, indicated by the student self-selected identification code. With such a small sample size and missing data about students' majors, comparisons of each combination were not computed. Instead, a comparison of the scores of those that completed the Intro course to those who did not and a comparison across the three majors were analyzed by separate ANOVA tests.

Table 8: Pre-course survey respondents grouped by major and completion of Introduction to Green Engineering

	Major				
Introduction To Green Engineering	**Unknown**	**CEE**	**ISE**	**ME**	**Totals**
Yes	3	1	2	3	9
No	11	1	2	5	19
Totals	14	2	4	8	28

For the Intro/no Intro comparison, *"List the 4 main phases of the life cycle of a product, process, or system,"* and *"List 3 general inputs and 3 general outputs for products or processes that would be included in an LCA,"* were the only questions with a significant difference with $p < 0.001$ for both tests. Students that completed Introduction to Green Engineering scored averages of 3.00 and 4.33 on those two questions respectively, while students without the background in Green Engineering scored averages of 0.95 and 1.21.

When comparing across majors, *"Describe 3 benefits of Life Cycle Analysis for engineering products, processes, or systems,"* resulted in a $p < 0.05$. For this question, the CEE students had an average score of 2.5, with an ME score of 1.0 and ISE score of 0.75. *"List the 4 steps to completing a Life Cycle Analysis,"* had a $p < 0.002$; for this question, both CEE and ME scored 0.0, while ISE averaged 0.75. Note that three of the four ISE-identified students each received 1 point on this question for answers similar to "interpretation of results."

3.1.2: Confusing Topics

On both of the minute surveys, the instructor asked students to indicate topics from class they did not fully understand. On the first minute survey, 13 students replied that nothing was confusing, but the connotations associated with "not sure" and "I can't think of one" are negative, whereas "[e]verything is fine" provides a feeling that the student understands all the topics. While 10 students mentioned specific content areas, the student replying "[q]uiz material" seems to be confused about all the content areas mentioned by other students. Table 9 summarizes the students' responses.

Table 9: "*What question, topic, or issue covered so far is the least clear?*" from Minute Survey #1

Category	Number of Responses	Majors	Description/Sample Comments
LCA phases	3	ME	• Boundaries between the different stages • Details of an LCA
Calculation of energy	2	ME	• "How do you calculate energy" • Specifically for the production and manufacturing phases
Materials	2	IDS	• "[B]iological materials are vague" • "Materials properties"
Manufacturing processes	1	ME	• "Deformation"
Environmental impact categories	1	--	• "Midpoints, Endpoints"
Content	1	--	• "[U]nsure of how some of the newest material will fit into the rest of the class"
Other	1	ME	• "Quiz material" (which encompasses all of the other categories)

No comment	13	ME
		CEE
		ISE
			• Positive connotation (1)
			  ○ "Everything is fine"
			• Neutral (8)
			  ○ Blank response
			• Negative connotation (4)
			  ○ "[N]ot sure"
			  ○ "I can't think of one"

On the second minute survey, the question asked students to reflect only upon subjects from the past week that remained unclear. The students felt that they needed more instruction on the software, SimaPro. A number of students expressed that they were struggling with some concepts covered in class; Table 10 lists the specific content areas as well as the other areas of concern.

Table 10: "*What question, topic, or issue covered <u>this</u> <u>week</u> is the least clear?*" from Minute Survey #2

Category	Number of Responses	Majors	Description/Sample Comments
SimaPro	8	ME ISE	• Lack of experience with the software • Complexity of the software
Data	3	ME CEE	• Gathering data • Evaluating the quality of data from databases
LCIA*	2	ME	• "LCIA"
DALY#	1	ISE	• "DALY is a little fuzzy, but not terribly so"
Classification	1	ISE	• "Classification"
ISO methods	1	--	• "ISO methods"
No comment	12	ME CEE ISE IDS	• Blank response • "Nothing"

***Note: Life Cycle Impact Assessment (LCIA)**
#Note: Disability Adjusted Life Years (DALY)

3.1.3: Content Coverage

In the second question of the post-course survey, the students were asked to evaluate the instructor's coverage of the important course topics. A table of the course topics was created in conjunction with a Likert-scale (see Table 11). The overall mode of the topics was the "about right" rating, indicating most students felt the topics were covered sufficiently. For "Materials Selection," "Streamlined LCA methods," and "Use of LCA in design," the "needing a little more focus" category was selected with almost the same frequency as the neutral rating. Students also felt that these two topics were not covered in enough detail. Students selected the "more focus" categories for both "SimaPro LCA Software" and "Sources for LCA data."

Table 11: "*Indicate your thoughts concerning the level of coverage in the class on the topics below by placing a check in the appropriate boxes*"

Topic	Need a lot more focus	Need little more focus	About right	Need a little less focus	Need a lot less focus
Extraction	0	0	18*	1	0
Manufacturing	0	3	15*	1	0
Use	0	3	14*	2	0
Disposal	0	1	16*	2	0
Materials Selection	0	8#	10*	1	0
Environmental Impacts^	0	4	13*	1	0
LCA methodology^	0	6#	12*	0	0
SimaPro LCA Software	3	10*	3	3	0
Sources for LCA data	3	10*	6#	0	0
Streamlined LCA methods	1	7#	11*	0	0
Use of LCA in design	2	8#	9*	0	0

^Note: One student did not make a selection for the indicated topics.
***Note: Indicates the mode of the student responses.**
#Note: Indicates the number of students checking this category is relatively large (≥ 1/3 of respondents)

Also on the post-course survey, one CEE student commented that "more time could be spent in understanding the impact categories." This response was common to the first formative survey, but from the overall content coverage question, the majority of the students felt the environmental impacts were adequately addressed during the semester.

3.1.4: Comparing Individual Students' Gains on the Cognitive Questions

Figure 4 displays a comparison of 15 individuals' average scores from both the pre- and post-course surveys. This graph shows general gains of Green Engineering and LCA content knowledge for each student in the trimmed data set. The overall average for the pre-course survey was 24.76%, while the post-course survey average was 67.62%. The vertical line indicates a "pass rate" of 66.67%, chosen because most questions most questions had a maximum possible score of multiples of 3. While every student shows improvement from the pre-course survey, only 7 of the 15 students earned scores higher than the pass rate.

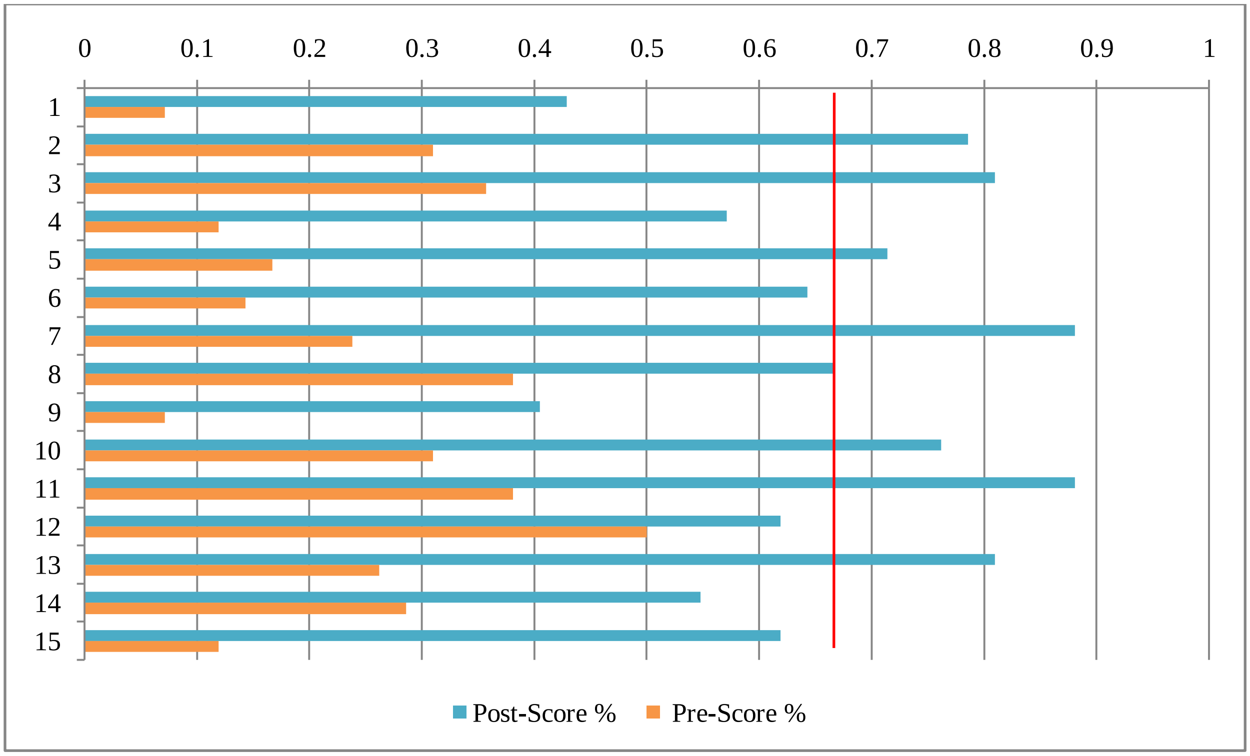

Figure 4: Original average scores of pre- and post-course surveys for each individual

Note: The red line indicates the "pass rate" of 66.67%.

3.1.5: Comparisons for Gains of Each Cognitive Question

The original scores from the trimmed dataset were entered into JMP [114] to complete the paired t-test analysis. From this analysis, the difference between the students' scores on the pre- and post-course surveys was found to be statistically significant, with α equal to 0.05, for 8 of the 10 questions. Further analysis on questions with multiple parts, questions 5, 7, and 8, revealed significant gains for each of the sub-questions.

Table 12: Summary of the pre- and post-course comparison statistics

		Average Score		Standard Deviation		Paired t-test
Coding Scale	Question	Pre-Course	Post-Course	Pre-Course	Post-Course	p value
0-3	1. List 3 specific examples of how engineering practice can have adverse environmental impacts	1.53	2.00	0.99	0.92	0.0684
0-3	2. Describe 3 benefits of Life Cycle Analysis for engineering products, processes, or systems	1.20	1.53	1.01	0.64	0.2377
0-3	3. Describe 3 limitations for using Life Cycle Analysis for engineering products, processes, or systems	0.60	2.13	0.63	0.64	<0.0001*

		Average Score		Standard Deviation		Paired t-test
Coding Scale	Question	Pre-Course	Post-Course	Pre-Course	Post-Course	p value
0-4	4. List the 4 steps to completing a Life Cycle Analysis	0.27	1.73	0.46	1.62	0.0046*
0-4	5. List 2 advantages and 2 disadvantages of using stream-lined LCA compared to full LCA	1.13	3.07	1.12	1.39	0.0006*
0-4	6. List the 4 main phases of the life cycle of a product, process, or system	1.67	3.87	1.50	0.35	<0.0001*
0-6	7. List 3 general inputs and 3 general outputs for products or processes that would be included in an LCA	2.33	5.33	2.29	1.59	0.0022*
0-9	8. List any 3 major environmental impact categories along with a potential midpoint and endpoint associated with each category	0.40	5.47	1.12	3.38	0.0002*
0-3	9. List 3 specific sources, one from each general category, where you can find quantitative environmental data	0.87	1.87	0.64	0.74	<0.0001*
0-3	10. List 3 risks for not considering the environment in the design stage for a product, process, or system	0.40	1.4	0.51	0.99	0.0042*

***Note: indicates statistical significance with $\alpha=0.05$**

Since the questions had different maximum possible scores, the average scores were normalized by dividing by the maximum for the question. Figure 5 displays normalized averages for each question of the pre-/post-course survey; the stars indicate significant gains, and the vertical line again represents the 66.67% "pass rate."

For this group of students, gains were significant for questions 3 though 10. Questions 1 and 2 did not have results of significant gains; both of these questions had relatively high pre-course scores. Questions 1, 3, 5, 6, and 7 were the only questions where the average of the group of students reached or exceeded the pass rate. The overall averages on questions 8 and 9 were above 60%, meaning environmental impacts and data sources needed a little more attention. Students did relatively poorly on questions 2, 4, and 10; these questions addressed the benefits of LCA, the steps of LCA, and importance of design.

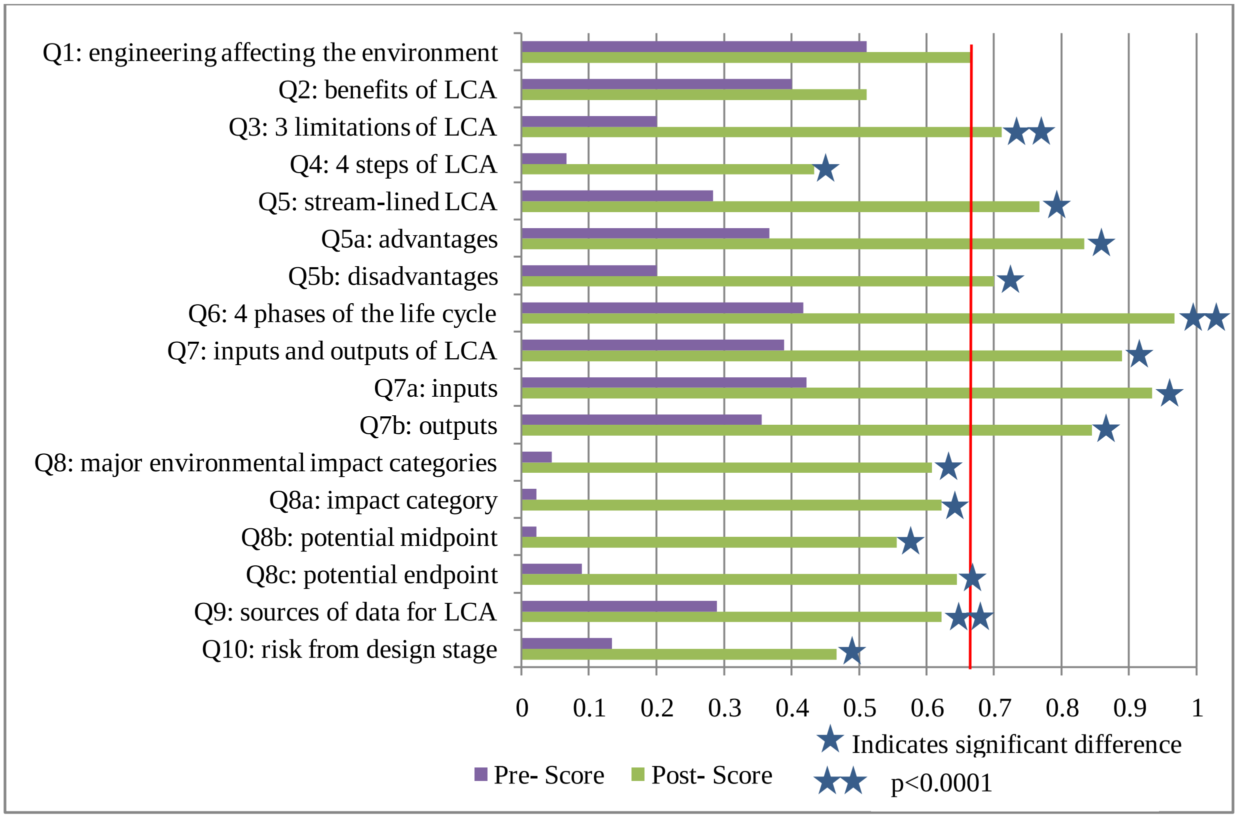

Figure 5: Normalized average scores from pre- and post-course surveys

Note: Stars indicate a significant difference between the two scores.
Note: The red line indicates the "pass rate" of 66.67%.

3.2: General Challenges of Teaching

Collectively, the study data reflects four general teaching challenges posed by the course: motivation and engagement, course structure, technology, and clarity of outcomes.

3.2.1: Personal Motivation and Engagement

3.2.1.1 Motivation

On the pre-course survey, students were given a checklist of ten categories plus an "other" option to describe their motivation for taking Environmental Life Cycle Analysis & Materials Selection. Figure 6 shows the data gathered about student motivation for enrolling in the course; the categories listed in the figure are ordered as they appear on the pre-course survey. These categories were determined from the pilot pre-course survey; a description of each category follows:

- Green Engineering concentration – student is pursuing the Green Engineering concentration
- Engineering Science elective – course fulfills a core curriculum requirement
- Co-op/Internship – student had/has an co-op or internship related to Green Engineering
- Interest from the course description – chosen from course description when registering

- Concern about the environment – personal interest regarding environmental issues
- Green Engineering career – pursuing a career in Green Engineering
- Foreseen value beyond graduation – possible benefits in future career, not necessarily in Green Engineering
- Résumé builder – course will "stand out" on a résumé
- Diversifying education – chance to "explore" Green Engineering
- Different perspective of engineering – gaining an environmental perspective

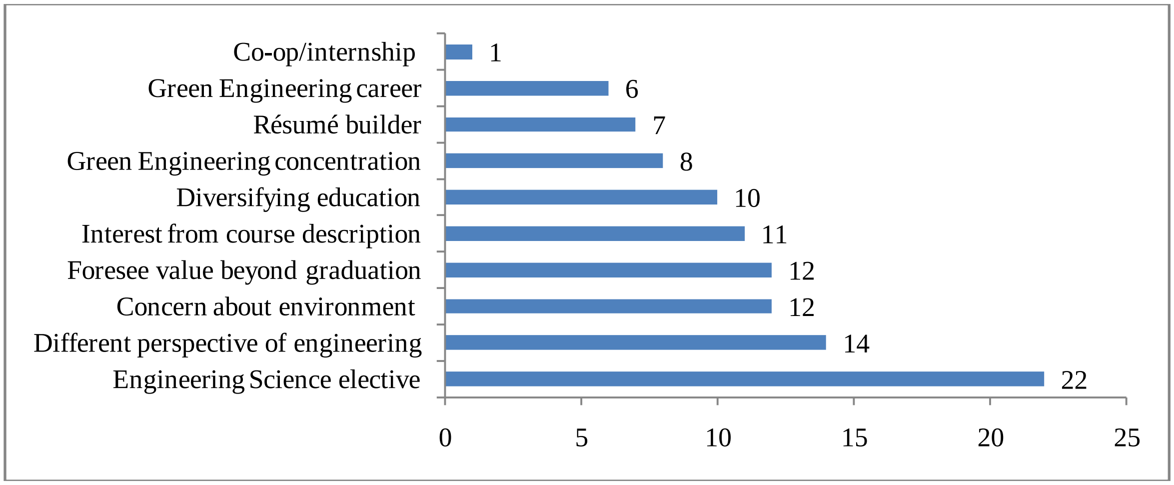

Figure 6: "*Why are you taking this class? (check all that apply)*"

Broader categories of "fulfilling requirements, "personal interest/concern," and "external motivators" were established to further investigate student motivation. The aggregate results are shown in Figure 7. Fulfilling Requirements includes taking the course for the Green Engineering concentration and using the course as an Engineering Science elective. Interest from the course description, concern about the environment, foresee value beyond graduation, diversifying education, and gaining a different perspective of engineering are included in Personal Interest/Concern. Lastly, External Motivation includes co-op/internship, Green Engineering career, and résumé building. Table 13 summarizes how the motivation categories listed on the pre-course survey are grouped into the broad student motivation categories.

Table 13: Itemization of the broad motivation categories by the categories listed on the pre-course survey

Broad Motivation Category	Type of Motivation	Motivation Categories from the Pre-Course Survey
Fulfilling Requirements	Extrinsic	• Green Engineering concentration • Engineering Science elective
Personal Interest/Concern	Intrinsic	• Interest from the course description • Concern about the environment • Foresee value beyond graduation • Diversifying education • Gaining a different perspective of engineering
External Motivators	Extrinsic	• Co-op/internship • Green Engineering career • Résumé building

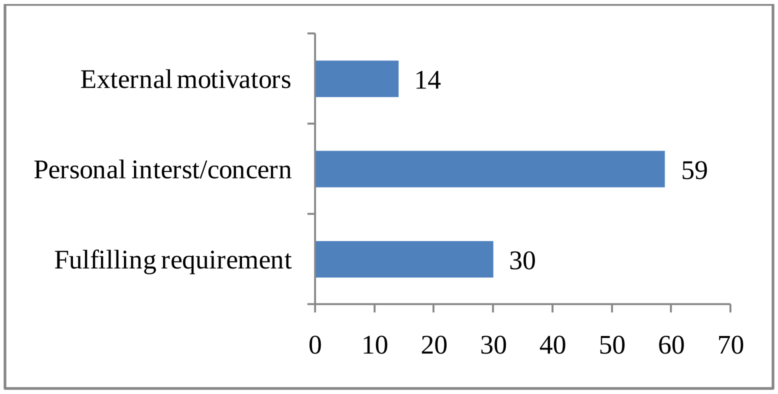

Figure 7: Student responses to influencing factors for enrollment expressed as broad motivation categories

On the post-course survey, students also mentioned motivation, as summarized in Table 14. In particular, not all the students were motivated to work on the team project, as seen in some of the comments. Some of these motivational factors included factors from the course, such as the Pass/Fail grading option of students. Conversely, a student felt intrinsic motivation by having a choice of product to analyze in the project. Lastly, a student commented on interdisciplinarity being a "job skill," which may have influenced his/her enrollment in the course or level of participation on the project.

Table 14: Themes of motivation from the post-course survey

Category	Number of Responses	Majors	Description/Sample Comments
Teamwork	3	ME	• "My team members weren't all that enthusiastic about doing the project. … We set goals … that were not met. … [A]ll teams are usually the same – there are those that want to do the work and those that don't" • "My group was quite unmotivated to begin the project" • "[M]ore should be done to encourage participation from all team members"
Course	2	ME	• Students taking the class P/F • Graduating seniors
Choice	1	ISE	• "I think the project difficulty was influenced by the product each group chose. I liked this about the project."
Interdisciplinarity	1	--	• "This is a skill that I have been asked for in job interviews"

3.2.1.2 Engagement

Like motivation, engagement emerged as a theme across multiple data sets. Figure 8 shows the third question on the first formative survey, student perception about the format of the class relating to the level of engagement during lecture-based instruction. While over half of the respondents said the class was interesting, eight students indicated lecture was “tolerable” and one individual was “bored” during class. One student from the tolerable group wrote “[m]ore [i]nteraction would be nice.”

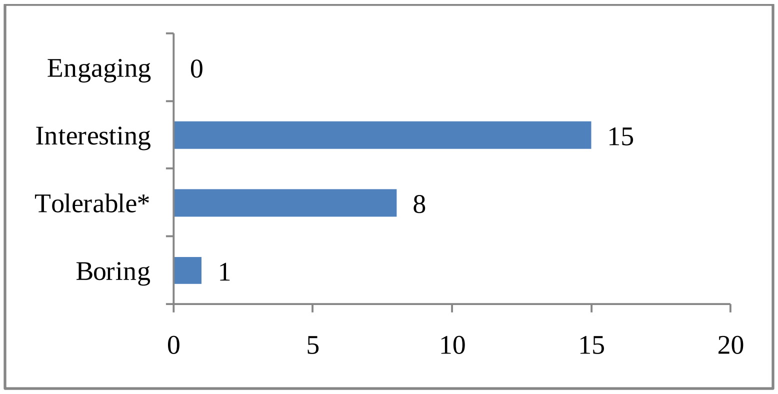

Figure 8: “*The format of this class is:*”

***Note: One student wrote in “More Interaction would be nice”**

On this same survey, students indicated other aspects of engagement. Most of these comments were positive aspects of engagement, but a few students contributed negative comments. Generally, students found the statistics presented in class to be interesting, and therefore engaging. Comments about the instructor’s enthusiasm and knowledge were also taken as positive comments relating to engaging the students. Negative comments included students expressing interest in having more in-class discussion and one student being “lost.”

Table 15: Categories of engagement from the first formative survey

Category	Number of Responses	Majors	Description/Sample Comments
Instructor	9	ME ISE CEE	• Enthusiasm in the classroom • Knowledge of the course topics • “Application of theories to real life situations”
Statistics	3	ISE	• “[O]nly 1% of the energy from burning gasoline in a car is used to move the driver” • “[F]uel cells are less ‘green’ than people make them out to be”
More engagement	14	ME ISE CEE	• “[E]ncourage note-taking” • “[M]ore class discussion” • Suggestion to discuss “hot button environmental issues”
Lost	1	ME	• “I felt like I should have taken the intro”

Question 2 of the second formative survey addressed the level of student engagement in the class since the first formative survey. During this month, the instructor attempted to incorporate more discussion into the lecture. Figure 9 shows that class instruction at least maintained the same level of engagement that the students had perceived prior to the first formative survey. Nearly half of the students indicated the class was becoming more engaging.

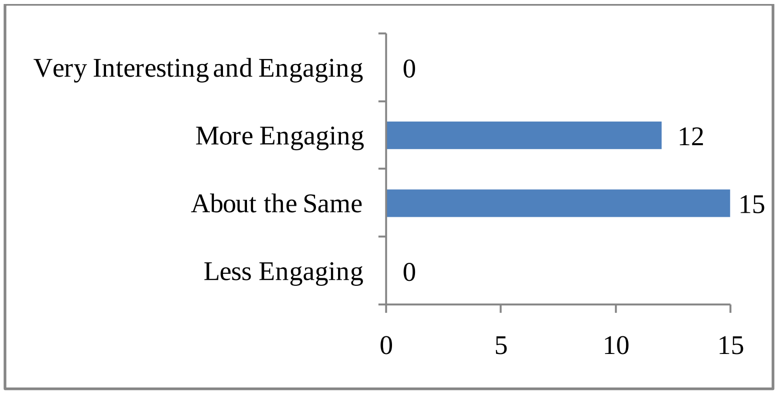

Figure 9: "*Since the last survey, the degree to which the lectures engage the class has been (circle one):*"

Again, the students expressed similar praises and concerns about the level of engagement in the classroom. Positive comments only included the statistics presented in the classroom, unlike the previous formative survey also including qualities of the instructor. Fewer students suggested "more engagement" in the classroom, which can be viewed as a positive from the previous formative survey. An additional negative directly linked to the pedagogy of lecture arose from this survey. Also, the student previously "lost" is now feeling more disengaged from the course and content. Table 16 summaries the themes and comments from the second formative survey relating to engagement.

Table 16: Summary of themes relating to engagement on the second formative survey

Category	Number of Responses	Majors	Description/Sample Comments
Statistics	3	ISE IDS	• Class lectures/discussions about: ○ Ethanol ○ Conservative tillage ○ Carbon Dioxide
More engagement	6	ME	• "[B]ring up more current events" • "[C]onversation topics are too specific and technical" • "[M]ostly our fault for not speaking up when asked"
Pedagogy	1	ISE	• "Lecture is still hard to pay attention to"
Lost	1	ME	• "I am now seriously questioning why I am here"

Level of engagement was also present on the post-course survey. Students again expressed interest in having more in-class discussion, but now they began to give more concrete suggestions of topics for in-class discussion. Even though the students were not asked to reflect on the level of engagement, two students did reflect on the students' role in in-class discussions. The last theme of "pedagogy" was developed because the students comment directly linked the pedagogical strategy of in-class discussion to learning. Table 17 summarizes the post-course survey comments regarding engagement.

Table 17: Responses from the post-course survey with respect to engagement

Category	Number of Responses	Majors	Description/Sample Comments
More engagement	7	ME ISE	• "More class discussions" • "[M]ore direction during the discussions" • "[Post] a reading before the materials is discussed in class – and discuss the reading in class" • "More assignments/activities that could help engage larger class discussions" • "[W]here students can relate their work experience or perspective"
Current events	2	ME ISE	• "More looking into environmental news happening currently" • "Assert more problems with industry"
Reflection	2	ME ISE	• "The first few weeks were rather boring since there was not a whole lot of class feedback. The rest of the class was very enjoyable because everyone seemed to open up more and provide more feedback to the class." • "The class got better once things became more discussions and more people were engaged"
Pedagogy	1	ME	• "The openness of the class – discussions, etc. – allowed for a greater understanding of the material"

From the classroom observations, the researcher noticed that during days when the instructor primarily lectured, several students would start falling asleep. It was also not uncommon to see students working on assignments for other classes. Very few students brought laptops to class, but one student would habitually bring his. This student would generally be working on his laptop during the lectures. In addition to falling asleep or doing outside work, a number of students would skip class. Even though the instructor would base part of the students' final grades on "in class exercises," a few students seemed not to be motivated by the 5 percentage points.

During the beginning of the semester, when the instructor tried to engage the students in discussion, only one or two students would participate. Even though they expressed that discussion made the class more interesting, students still seemed reluctant to participate in class discussions as the semester progressed. When the concept of weighting was introduced, and every student was required to make their own weighting scale and poll five other people, class discussion was high. Within the next few class meetings, the instructor held an open-class discussion about the projects; only a handful of people asked questions.

3.2.2: Course Structure

Several issues related to course structure also emerged as areas of concern, including: pace, course materials, homework assignments, supplemental readings, quizzes, and the team project.

3.2.2.1 Pace

For this study, the pace associated with the classroom was interpreted as the rate at which the instructor introduced and explained concepts. The first question pertaining to the pace of the course was asked on the first formative survey. Almost unanimously, the average response showed the students believed the pace of the class was "about right." Figure 10 shows the distribution of students' answers.

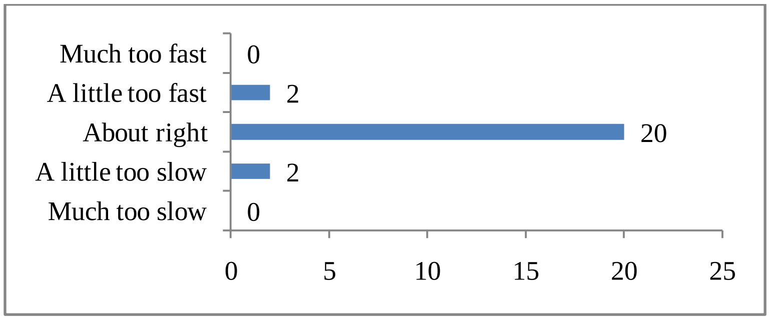

Figure 10: "*The pace of this class so far is (circle one):*"

The only other mention of pace was on the post-course survey. In the question asking students for any suggestions on how to improve the course for future semesters, an industrial design student commented that "It seems like the pace of the class is really fast for the first half of the semester and then it slows considerably in the second half."

3.2.2.2 Course Materials

In general, students also felt that some improvements could be made to the materials used in the course. In addition to homework assignments, supplemental readings, quizzes, and the team project, students commented on the use of course management software and the content of lecture slides. Specific comments of the general course materials showed up on both of the formative surveys and the post-course survey. Table 18 summarizes the "good aspects" and "areas for improvement" of the course materials from the students' perspective. The "good aspects" were only present on the first formative survey, whereas the "areas for improvement" appeared on both formative surveys and the post-course survey.

Table 18: Summary of student comments on the course materials in general

Category	Number of Responses	Majors	Description/Sample Comments
Good aspects	8	ME ISE	• Instructors use of course management software • Content on lecture slides • Use of charts and graphs
Areas for improvement	7	ME ISE CEE	• "Handout of koofers to prepare for the quiz" • "Having lecture notes up the night before class • "More Audio/Video" • "More context & idea description, Less data" • "[M]ore pictures, less text on slides" • "[L]ess intensive quizzes" • "Lecture notes are still posted late"

3.2.2.3 Homework Assignments

While the instructor did not specifically ask about the homework assignments on the first formative survey, students did provide some feedback pertaining to homework on other questions. The second formative survey included a Likert-scale question on the effectiveness of homework in reinforcing the concepts covered during class. The majority of students viewed the homework as reasonably effective, but three students questioned the homework's effectiveness, as seen in Figure 11. A student also provided feedback relating to homework assignments on an open-ended question of improvements the instructor could make to the course. The student feedback on both formative surveys and the post-course survey included both positive and negative responses, as shown in Table 19.

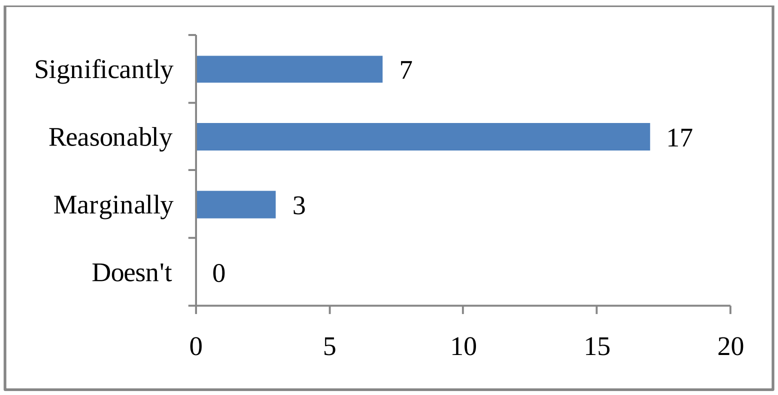

Figure 11: "*Comment on the effectiveness of the homework to reinforce and/or apply your knowledge of concepts covered in class (circle one):*"

Table 19: Summary of responses students provided regarding the homework assignments

Category	Number of Responses	Majors	Description/Sample Comments
Good aspects	2	ME	• "[H]ow [homework assignments] tie in to each other" • "I feel that the homework was needed to help clarify the course"
Areas for improvement	25	ME ISE CEE	• Unsure how the assignments are graded • "Give assignments 2 weeks in advance" • "I don't like the memo style HW" • "[E]xtremely time consuming" • "Some of the homework required a lot of research to be completed"

The post-course survey included two questions relating to homework. The first question asked students to evaluate the amount of homework. Overall, the majority of students felt there was more homework than necessary for the course, as shown in Figure 12. The students' comments focused on the amount of research that was necessary to complete the homework assignments. The open-ended responses are included in Table 19, since the nature of the responses aligned with the "area of improvements" category pertaining to homework assignments.

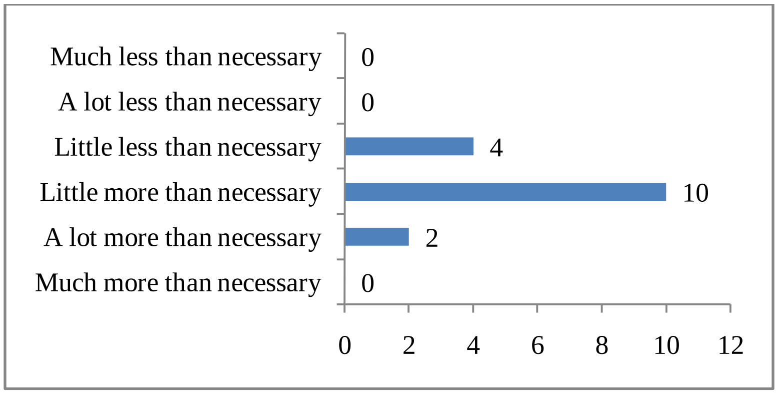

Figure 12: "*Rate the amount of homework in this class*"

As a follow-up, the next question asked students to rate the difficulty of the homework assignments. The distribution of responses leaned toward the difficult side of the Likert-scale, as shown in Figure 13; the open-ended responses also were incorporated into Table 19. The reasons for rating the homework difficult were the troubles associated with finding resources and the amount of time required for the research. A student recalled being offered a library session at the beginning of the semester; the instructor held a vote, and the students indicated they did not want the library session.

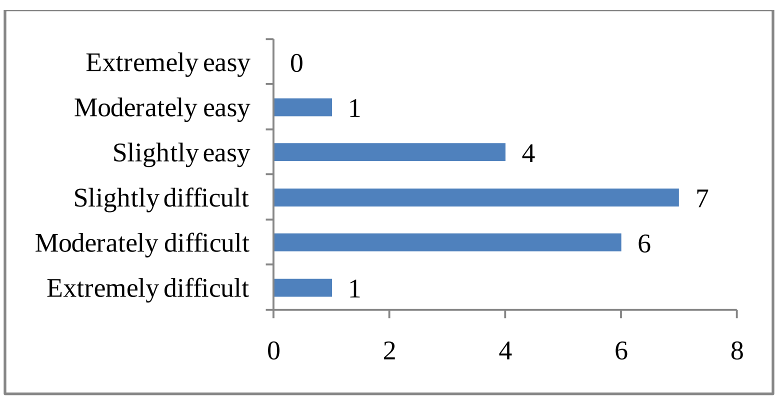

Figure 13: "*Rate the difficulty of homework*"

3.2.2.4 Supplemental Readings

Unlike homework assignments, the students were never asked specific questions related to the supplemental readings on either formative survey. The students did provide comments, mostly in the "areas for improvement" category on the formative surveys. The data from the formative surveys and the post-course survey is summarized in Table 20 as "good aspects" and "areas for improvement" relating to the supplemental readings.

Table 20: Student comments of the supplements readings from both formative surveys and the post-course survey

Category	Number of Responses	Majors	Description/Sample Comments
Good aspects	4	ME ISE	• "The readings could be a bit long sometimes, but the fact that they were interesting helped get through them" • "Most of the articles were useful and interesting" • "The amount assigned was about right" • "It helped me understand how the material is used and implemented"
Areas for improvement	12	ME ISE CEE	• Articles on "how LCA has been used in the real world" • "Readings unclear" • "[L]ess out of class reading" • "I think the lectures/discussions were more useful in cementing ideas" • "The readings weren't discussed very much in class"

Additionally, students rated the amount of reading materials for the ninth question of the post-course survey; the distribution of ratings for this question is shown in Figure 14. While most students ranked a "little more," when grouped with a "little less," these rating essentially become neutral.

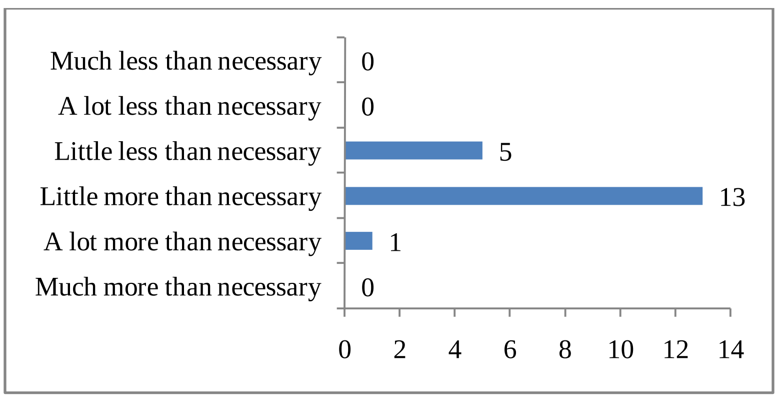

Figure 14: "*Rate the amount of the reading material*"

Following-up on the previous question, the students were asked to rank the usefulness of the reading materials. Figure 15 shows that students almost unanimously rated the readings as useful. Overall, the students seemed to think the supplemental readings were useful.

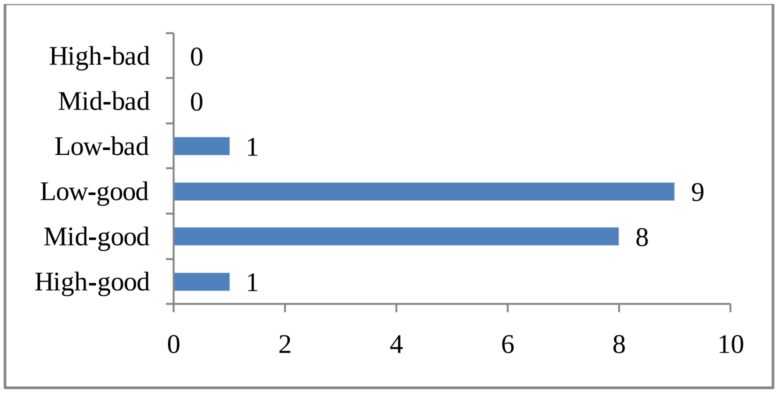

Figure 15: "*How useful was the supplemental reading material in helping you learn the class concepts by providing another perspective*"

3.2.2.5 Quizzes

Only on the post-test survey, students were asked to rate the difficulty of the in-class quizzes. Figure 16 shows the majority of students felt the quizzes were "slightly difficult." While the majority of the students chose a rating on the difficult side of the Likert-scale, only one student provided a negative comment of feeling "pressure;" the remaining student comments had positive connotations and do not directly relate to the level of difficult as presented in Figure 16. The summary of student responses to the difficulty of the quizzes is presented in Table 21.

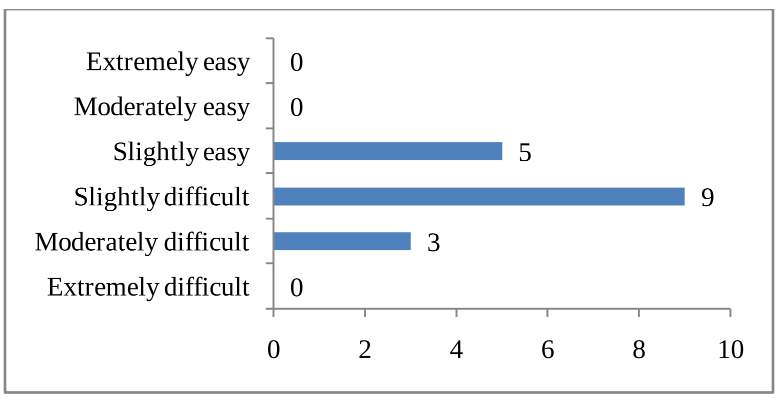

Figure 16: "*Rate the difficulty of quizzes*"

Table 21: Student responses on the difficulty of quizzes

Category	Number of Responses	Majors	Description/Sample Comments
Good aspects	5	ME ISE	• "Very fair" • "Good quizzes allowed for easy answering" • "They required you to know what's been going on, but never too detailed" • "The quizzes were relevant and were easy when you paid attention in class – what a difference that makes!"
Areas for improvement	1	ISE	• "Having unannounced quizzes and no tests puts a lot of mental pressure on knowing all the material at all times. More information would be learned if the quizzes were all planned at the beginning of the semester and class attendance was higher weighted."
Other	1*	ISE	• "I'm not sure I've taken enough quizzes to accurately comment. We spent a lot of time on disposal and that was one of the easier topics so that quiz was easy. First quiz I didn't know what to expect. Second quiz was difficult but you said you knew that and would account for that."

***Note: Indicates students that did not select a ranking on the Likert-scale.**

3.2.2.6 Team Project

Question 8 of the post-course survey asked students to reflect on the difficulty of the project. The majority of responses fall on the difficult side of the Likert-scale, as shown in Figure 17. Most of the students' comments for this question are not directly related to the difficulty of the project. Comments on motivation of team members and difficulties in scheduling meetings are addressed elsewhere in this thesis. For this question and a follow-up question on suggested improvements to the project, several responses did relate directly to the project; these comments are summarized in Table 22. While most of the comments are suggestions for improvements, some students also thought the project was fine.

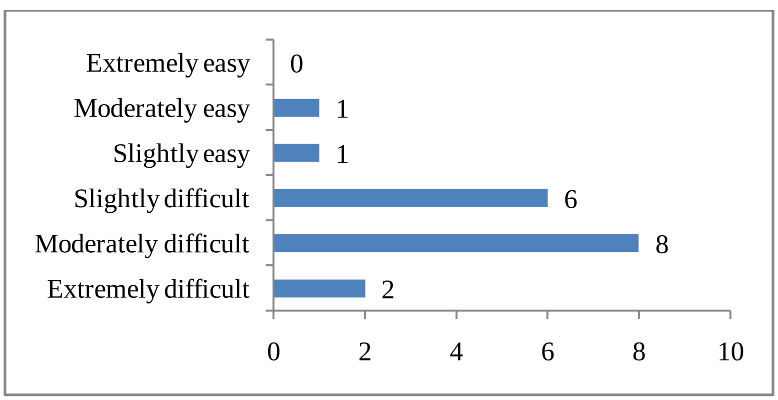

Figure 17: "*Rate the difficulty of the project*"

Table 22: Students' reasoning for rating the difficulty of the project

Category	Number of Responses	Majors	Description/Sample Comments
Begin earlier	4	ME ISE CEE	• "I would start earlier" • "Start it earlier" • "[A] semester-long project with a timeline that coincided with class material"
Amount of research	3	ISE	• "A lot of time was spent trying to collect data but only resulted in a small percentage of the project"
Instructor checkups	2	ME IDS	• "Have set meeting times for each team each week and randomly check to see if they are meeting"
No change	2	ME	• "I think the structure of the project is good as-is" • "I thought the structure was good"

3.2.3: Technology

After the instructor introduced SimaPro in class, students began expressing their feelings towards software, both in general and specific to SimaPro. One student supported his level of recommendation of the course to other students in the same discipline by expressing, "I dislike classes where I am asked to learn new software." Table 23 displays the positive and negative features of SimaPro as expressed on the second formative survey after initial introduction to the software, whereas Table 24 summarizes the responses on the post-course survey of the students' experiences of working with SimaPro on the project.

Table 23: Student responses related to the software on the second formative survey

Category	Number of Responses	Majors	Description/Sample Comments
Good aspect	10	ME CEE	• "How to use SimaPro" • Being introduced to functions and/or capabilities of SimaPro
Areas of improvement	9	ME ISE	• Lack of experience with the software • Complexity of the software • "Work with SimaPro, unclear/hard to use"

Table 24: Post-course survey comments relating the software to the team project

Category	Number of Responses	Majors	Description/Sample Comments
Difficulty	4	ME ISE	• "[T]he software was difficult to navigate through" • "Need more SimaPro training/exercising in class" • "[S]ometimes things wouldn't save in SimaPro resulting in lost work."
Areas of improvement	4	ME ISE	• "[SimaPro is] quite frustrating to work with" • "SimaPro was difficult to use" • "[L]ess SimaPro" • "Do more work in SimaPro to help us [with] the project"
Division of work	3	ME	• "I would have everyone do a part in SimaPro" • "It's hard to share the workload when much of it falls on the SimaPro expert" • "SimaPro … is basically one persons job"

3.2.4: Clarity of Outcomes

Students' understanding of outcomes emerged as a final category of general challenges of teaching. The outcomes include both course learning objectives and expectations of the group project.

3.2.4.1 Course Outline and Objectives

The last Likert-scale question of the first formative survey asked how clearly students understood the course outline and the learning objectives. As seen in Figure 18, the majority of the students had a notion of the sequence of topics and the learning objectives, but five students were unsure of the course outline, the learning objectives, or both.

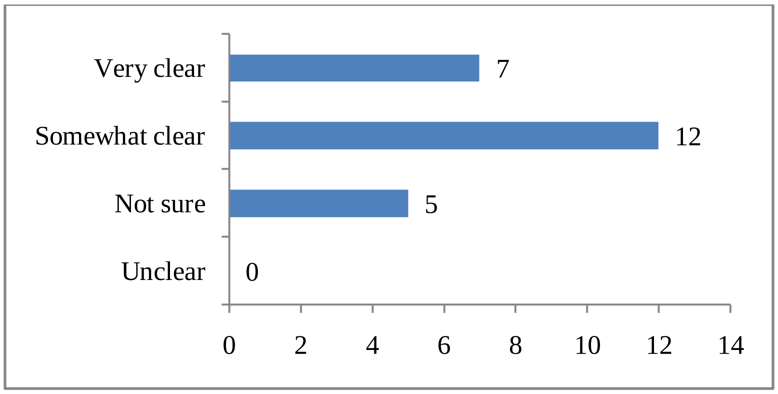

Figure 18: "*How clear are the course outline and learning objectives for the class?*"

3.2.4.2 Understanding of the Group Project

Figure 19 shows the student understanding of the expectations from the group project, as reported on the second formative survey. The instructor provided written instructions, verbally explained the project, and answered students' questions during class, yet the survey results show that more than half of the students were still confused about the expectations of the group project.

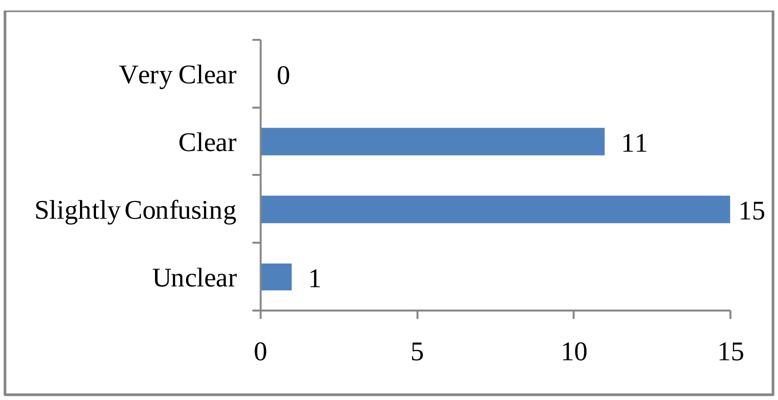

Figure 19: "*Based on the written project assignment and class discussions, the expectations for the group project are (circle one):*"

3.3: Challenges Unique to the Interdisciplinary Nature of the Course

While both surveys and observations yielded general insight about teaching useful to any instructor, the data also highlights two primary challenges associated with interdisciplinary courses. In particular, structural issues and disciplinary egocentrism emerged as the unique challenges.

3.3.1: Structural Issues: Team Organization

Structural issues associated with team organization represent one important theme for interdisciplinary instructors. The majority of responses related to the group project were on the post-course survey, since the instrument included five questions asking the students directly about the project. On the second formative survey, one student did suggest having fewer students in a group because of conflicting schedules. Table 25 summarizes the students' responses of how the interdisciplinary nature of the course affected the team project.

Table 25: Summary of students' responses of how the interdisciplinary nature of the course affected the team project

Category	Number of Responses	Majors	Description/Sample Comments
Scheduling	13	ME ISE IDS CEE	• "Having to work around everyone's schedules was a bit tedious" • "[H]ard to make a coherent project without constantly being in contact with one another" • "[D]ifficult to get others together" • "Interdisciplinary teams are hard to work with as seniors because all different majors' schedules are hard to coordinate"
Division of work	7	ISE IDS	• "Cases exist where it would be convenient to call upon one persons expertise to solve a problem" • "[D]ifferent specialties … created a simple way to break up the work" • "Students in other disciplines often have different strengths that may be my weakness' thus creating a higher quality end product but not necessarily allowing all members of the team to learn as much about different aspects of the project" • "There is the potential for team members to use the knowledge specific to their discipline to better complete certain aspects of the project"
Group size	5	ME ISE IDS	• "[O]ur group was rather large which made it more difficult to meet and agree on ideas" • "For students to learn the most about the material, the projects should be individual tasks. Team projects should be saved for in major classes." • ""I think the project might be better as something individual but a little more condensed"
Interesting	2	ISE CEE	• "It was also interesting to work with people we didn't know" • "[I]t was more interesting"
Skills	1	ISE	• "We definitely had a broad range of skills in our group"
Conflict	1	ISE	• "Difficulty in resolving problems"
Familiarity	1	ISE	• "Didn't have the initial familiarity we would have [with] people in major we have known for a while"

3.3.2: Disciplinary Egocentrism: Relatedness

The second, and more fundamental, interdisciplinary challenge addresses disciplinary egocentrism. The first of two concepts associated with disciplinary egocentrism is relatedness. Relatedness refers to the connection between the interdisciplinary topic and a specific discipline.

3.3.2.1 Relevant Engineering Skills

The first instance of the relatedness piece of disciplinary egocentrism is the second Likert-scale question on the first formative survey. For this question, the students ranked the relevance of the class information with respect to necessary engineering skills for considering the environment. The students have conceptions, possibly naïve ones, of what these necessary skills are; these conceptions likely stem from their particular disciplinary background and the expectation of gaining these skills by taking a course in Green Engineering. The distribution of student answers (Figure 20) shows a favorable response, with only three students unsure of the relevance.

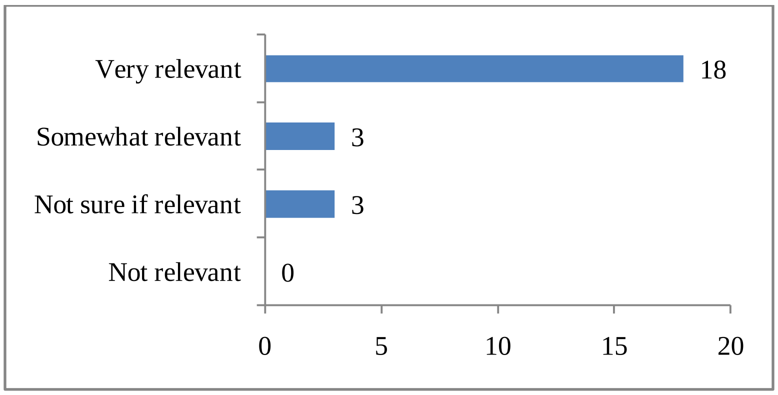

Figure 20: "*The relevance of the class information covered so far to what you think are important engineering skills with respect to the environment (circle one):*"

3.3.2.2 Green Engineering Content Knowledge

Other areas of relatedness appearing on the first formative survey included specific Green Engineering content knowledge. Table 26 summarizes the "good aspects," areas which students believe will be useful in the future, and "areas of improvement," topics that students did not fully understand.

Table 26: Summary of relatedness from first formative survey

Category	Number of Responses	Majors	Description/Sample Comments
Good aspect	17	ME ISE CEE	• Concept of Life Cycle Analysis • Specific parts of the life cycle • Environmental impacts
Areas of improvement	10	ME IDS	• Boundaries between the different life cycle stages • "How do you calculate energy" • "[B]iological materials are vague" • "Materials properties" • "Deformation" • "Midpoints, Endpoints"

Students' responses on the second formative survey also included the theme of relatedness. Again, "good aspects" include the topics which students identified as having positive value in the future, and "areas of improvement" were concepts that students did not fully understand. The responses from the second formative survey are summarized in Table 27.

Table 27: Relatedness comments on the second formative survey

Category	Number of Responses	Majors	Description/Sample Comments
Good aspect	10	ME ISE CEE	• Use of LCA in industry and government • Being introduced to new databases • How to use the information from databases • Concepts of weighting, double counting, and DALY ○ "I didn't exactly understand [double counting] before today, but now I do" ○ "The whole system with DALY"
Areas of improvement	8	ME ISE CEE	• Gathering data • Evaluating the quality of data from databases • "LCIA" • "DALY is a little fuzzy, but not terribly so" • "Classification" • "ISO methods"

3.3.2.3 Recommending the Course to Students in the Same Discipline

Students also mentioned issues of relatedness when describing their level of recommending the course to other students in their discipline. The first question on the post-course survey asks students to rank how likely they would be to recommend the course to other students in the same discipline; Figure 21 shows the majority of the class would positively (either "moderately" or "highly") recommend the class to students from their major.

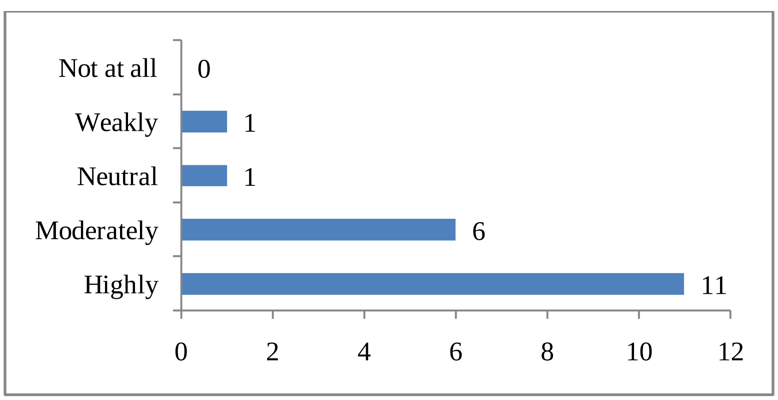

Figure 21: "*Circle the degree to which you would recommend this class to other students in your discipline:*"

The question then asked for the students to provide reasons why they would or would not recommend the course. All students responded to the open-response question to further explain their level of recommendation. Table 28 synthesizes student responses for the different levels of recommendation. The descriptions and sample comments are sorted into "positive" and "negative" categories from the connotation implied by the text of the response. The students that reflected on the content from Green Engineering and their discipline responded with "relatedness" comments; these comments were predominant in the "neutral" and "moderately" rankings.

Table 28: "*Explain why you would recommend the course at the level indicated*"

Category	Number of Responses	Majors	Description/Sample Comments
Not at all	0		
Weakly	1	--	• Positive ○ "[E]njoyed the class and the information" • Negative ○ Did not appreciate having to learn new software ○ "[S]ome of the [homework] was difficult."
Neutral	1	--	• Positive ○ Believed parts of the life cycle analysis may be useful • Negative ○ Product design is not the focus of his/her discipline
Moderately	6	ME ISE CEE	• Positive ○ Importance of green engineering ○ Gaining a different perspective of engineering • Negative ○ Examples not from the student's specific major ○ Not seeing the content as applicable to the student's major ○ Fulfilling a requirement and was "relatively painless" compared to other options
Highly	11	ME ISE IDS CEE	• Positive ○ Importance of green engineering ○ Gaining a different perspective of engineering

3.3.2.4 General Comments on Relatedness

Additional comments from questions 3, 4, and 9 on the post-course survey highlighted the challenge of relatedness. Questions 3 asked students to compare how product/process design in this class differed from other courses they have taken, question 4 had students rank the course for learning and usefulness and explain why, and question 9 asked students to rank the amount of reading material and elaborate their ranking. The responses to these questions associated with the relatedness factor of disciplinary egocentrism are summarized in Table 29.

Table 29: Relatedness comments from multiple questions on the post-course survey

Category	Number of Responses	Majors	Description/Sample Comments
Design constraints	9	ME ISE IDS CEE	• "Most other classes focus on other measures such as timelines, cost, or ergonomics" • "[Other classes] focus only on manufacturing costs and efficiency" • "Includes environment as design constraint"
Readings	6	ME ISE	• "Long readings are deterring" • "I'm not used to spending hours of reading articles" • "The readings could be a bit long sometimes, but the fact that they were interesting helped get through them" • "Most of the articles were useful and interesting"
Life cycle	4	ME CEE	• "[N]ever looked at the extraction and disposal phases" • "Other classes seem to ignore the extraction and disposal phases of life cycles"
Design experience	2	ME	• "[T]his is very new to me"
Relevance	1	--	• "This class provided a lot of interesting knowledge and ideas… but I'm not sure how relevant the knowledge will actually hold in my career"

Lastly, the notion of relatedness also was present in the student interview data, with the relevant data shown in Table 30. The students identified similarities and differences of methods and content knowledge presented in the Green Engineering course with respect to other courses in their major, in this case, Mechanical Engineering. The category of "readings" was also included because of the student's comment of the readings being "relevant," even though he did not completely read all of the supplemental readings.

Table 30: Summary of student interview data regarding the relatedness aspect of disciplinary egocentrism

Category	Number of Responses	Majors	Description/Sample Comments
Similarities	2	ME	• Energy balance; "mostly basic stuff I would have learned in, you know, my beginning engineering, like even just ESM classes" • Even though took a materials course, but learned more about production energy
Differences	2	ME	• Impact categories • "[W]e don't talk about [all life cycle phases] in ME at all" • "We might only look at the manufacturing and use" • "I think they mentioned LCA once in the [sophomore design] class, for five minutes" • "I feel LCA was an extension of what we've studied before, but it wasn't necessarily the same material"
Knowledge	1	ME	• LCA course was "a lot more conceptual than ME"
Readings	1	ME	• "I, I tried to read [the readings], but I didn't read all of them. I mean, I thought they were relevant, but also some were a little lengthy"

3.3.3: Disciplinary Egocentrism: Perspective

The second key dimension of disciplinary egocentrism is perspective, which refers to how a specific discipline intersects the interdisciplinary subject and connects with the other disciplines.

3.3.3.1 Comparison of the Affective Question: Importance of Environmental Design Constraints

One affective question was repeated on the pre- and post-course surveys. This question deals with the students' perceptions of the importance of environmental constraints in the design process compared to constraints of cost and performance. To simplify the survey, three statements were made comparing environmental constraints with cost and performance. These statements placed environmental constraints below, equal, or higher than cost and performance; see Appendix V, question 2 for the exact verbiage.

Figure 22 shows the original data from all pre- and post-course surveys collected. On the pre-course survey, one ME student selected the "higher importance" statement and wrote, "weighing them equally is fine as long as it really is equal, but it usually isn't." On the post-course survey, four students felt none of the options fully encapsulated their views, so they wrote the following answers in the "other" category:

- "I believe in [the last one (higher importance)] however - we must take baby steps to get there. A slow [metamorphosis] to that stage would be beneficial. People don't like drastic changes – especially if it costs the company [money]."
- "Performance and cost should be the key design criteria followed by environmental issues to the extent that they do not significantly affect the former and no environmental rules or regulations are violated, but the governments of the world must be informed and create environmental rules and regulations that make sense. The government should employ engineers and environmental experts for these positions, not politicians."
- "Concern for the environment will always in the long run create a more profitable company."
- "[Performance] and cost should be the key design criteria, but environmental issues should be a significant issue."

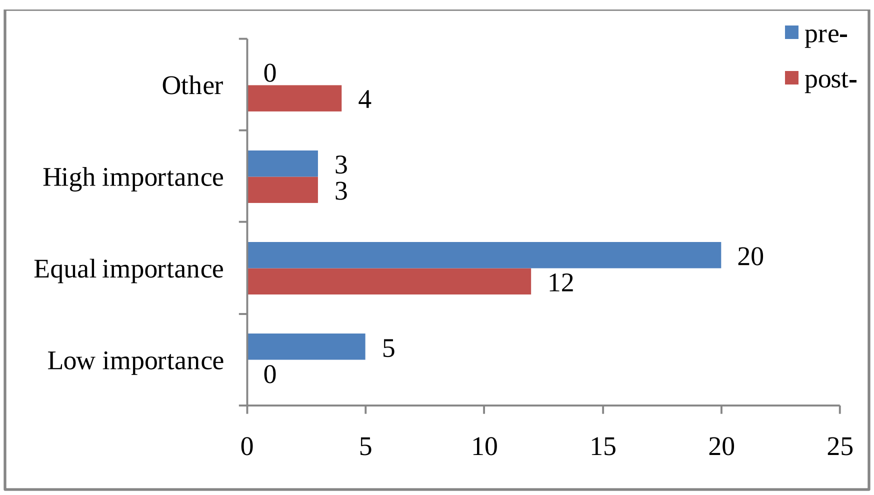

Figure 22: Original data for question 16, importance of environment design criteria relative to cost and performance

3.3.3.2 General Comments on Perspective

Students' responses on both formative surveys also included the theme of perspective. Two important themes are the consequences of engineering decisions and the differences in methods of analysis. The students viewed being made aware of consequences and different analysis methods as valuable knowledge for their future. The responses from both formative surveys are summarized in Table 31.

Table 31: Summary of perspective comments on both formative surveys

Category	Number of Responses	Majors	Description/Sample Comments
Consequences	3	ME ISE	• "[C]ause & effect" relationships • "[E]verything we use has some type of environmental impact whether small or little"
Methods	3	ME	• "To consider data and analyze results from [different] points of view which can give a very different outcome" • "[L]earning about how each type of environmental impact has different weights in analysis to different groups/people"
Perspective	1	ME	• "[L]ooking at production statistics, it gives a good perspective to engineering"
Design	1	IDS	• "[D]epth of perspective concerning all that is involved in producing consumer products"

The theme of perspective also appeared on the post-course survey in questions 3, 4, 11, 12, and 13. Questions 3 asked students to compare how product/process design in this class differed from other courses they have taken, question 4 had students rank the course for learning and usefulness and explain why, question 11 asked students to reflect and discuss how this experience differed from projects they have worked on in disciplinary groups, question 12 asked students to describe positive effects of working on interdisciplinary teams, and question 13 asked students to recount challenges of working with team members of different disciplines. Table 32 summarizes the comments of perspective from these post-course survey questions.

Table 32: Summary of the post-course survey responses related to perspective

Category	Number of Responses	Majors	Description/Sample Comments
Different viewpoints	8	ME ISE	• "We had different views coming from different disciplines regarding how to view the project" • "I noticed we definitely thought different and put more emphasis on different things" • Different perspectives "made it challenging to agree" • "They brought ideas & concepts to the group I never would have considered"

Different methods	8	ME
		ISE
			• Different approaches to a problem
			  ○ "[H]olistic approach"
			  ○ "You get … different ideas about how to attack the problem"
			• Different evaluation methods

Skills or knowledge	7	ISE CEE	• "We definitely had a broad range of skills in our group" • "Material science engineers had more in depth knowledge of the selection of materials for the project" • "Students in other disciplines often have different strengths that may be my weakness" • "The other members do not have the same classes that I do, so they may not have experiences with some things that I do" • "[D]ifferent levels of knowledge about different areas, particularly environmental impacts"
No differences	4	ME CEE	• "It wasn't drastically different, but it was more interesting" • "Interdisciplinary teams are not very different than non-interdisciplinary. It is still difficult to get others together and ideas are not radically different." • "The organization and the way we all worked was the same as all other projects I have been involved in"
Division of work	3	ISE IDS	• "Cases exist where it would be convenient to call upon one persons expertise to solve a problem" • "[D]ifferent specialties … created a simple way to break up the work" • "There is the potential for team members to use the knowledge specific to their discipline to better complete certain aspects of the project"
Broadness/ Complexity of design	2	ME ISE	• "[B]road scope of design" • Considering "all aspects of design"
Knowledge of other disciplines	2	--	• "Learning a little more about other disciplines was eye-opening" • Ability to learn "facts/thoughts/approaches you wouldn't get to see working [within] your discipline"
Importance of multiple viewpoints	1	ME	• "It takes another viewpoint to improve environmental impacts without sacrificing performance"

Lastly, the student interview data also contained comments on the perspective piece of disciplinary egocentrism. The students' interview responses on perspective were coded into three categories. Neither student mentioned any challenges associated with the different perspectives of disciplines; they both seemed to view working with students of different disciplinary backgrounds as learning experiences. Table 33 displays the relevant data from the interviews on perspective in disciplinary egocentrism.

Table 33: Summary of student interview data regarding the perspective aspect of disciplinary egocentrism

Category	Number of Responses	Majors	Description/Sample Comments
Methods	2	ME	• Methods of data collection • "I think just the whole idea of thinking about something in all those phases" • "[L]ooking at engineering problems holistically from beginning to end and, um, learning how to minimize impact"
Problem solving	1	ME	• "I feel like all of engineering is pretty much just problem solving in different areas"
Opinions	1	ME	• "I felt like people from, where bringing different opinions from their backgrounds, which I thought was interesting"

Chapter 4: Discussion

From the data and results, challenges of teaching this instance of Environmental Life Cycle Analysis & Materials Selection have been identified. Not all of these challenges are unique to this course; challenges associated with experience level of the instructor and interdisciplinary collaboration are examples that may be transferable to courses with similar settings – a new faculty member teaching a course or a course covering an interdisciplinary field. These challenges also pose opportunities for faculty to "think outside the box" and create novel, or adapt existing, pedagogical strategies for interdisciplinary courses.

While a number of these challenges are general to teaching any course, two areas of challenges unique to interdisciplinary courses emerged. First, the structure of the team project was a challenge for students to work effectively and efficiently to complete the assignment. Second, the faculty member faced the challenges of disciplinary egocentrism: 1) relating Green Engineering to all disciplines represented in the classroom and 2) revealing how each discipline fits into Green Engineering as well as the other disciplines.

4.1: Challenges General to Teaching

Not all of the challenges uncovered in this case study of Environmental Life Cycle Analysis & Materials Selection are unique to interdisciplinary courses. From analyzing the data, these general challenges are student motivation, engagement, software, pace, course outline/learning objective, and homework/reading assignments. Additionally, some of these challenges may be associated with the level of experience of the instructor.

4.1.1: Personal Motivation and Engagement

Student motivation was assessed through several instruments. On the pre-course survey, the students indicated numerous intrinsic (personal) and extrinsic (external) motivating factors for enrolling in the course. On the post-course survey, students wrote that motivation to participate in the group project was affected by the grading option students had for the course (either A-F or Pass/Fail), academic priority of each student on the team (seniors dedicated to completing their capstone design), or the personal disposition each student had towards teamwork (hard workers versus slackers). From the classroom observations, a number of students seemed unmotivated by participation points, the instructor's enthusiasm, and/or the lecture and discussion topics. This lack of motivation in the classroom should relate to the level of engagement students perceived throughout the semester.

Engaging students in the classroom was another challenge faced by the faculty member teaching this course. While the students kept requesting more in-class discussions, the instructor constantly encountered resistance expressed through lack of student participation. Weimer [115] dedicates a chapter of her book *Learner-Centered Teaching* to the types of resistance faculty members may face when using active learning pedagogical strategies in the classroom. In this case, the students exhibited passive resistance, with one interviewee reflecting directly on the level of participation during the in-class discussions: "there were times when I felt people should have been more engaged than they were." Few students ever gave ideas to improve the level of engagement, with a total of five suggestions gathered from minute survey #1, minute survey #2, and the post-course survey.

4.1.2: Course Structure

The concern about the pace of the class being fast at the beginning of the semester seems to be weakly supported. Prior to spring break, the instructor had eleven PowerPoint presentations and only eight for the remainder of the semester. The views on the pace of the class may have been altered due to the disruption near the end of the semester. When asked for the confusing topics on the formative surveys, students would mention a topic vaguely without a deeper reflection of what specifically was confusing about the topic. In order for students to gain clarification on a topic, they would have to ask the instructor questions – potentially an intimidating action for the students. Requiring a textbook or including supplemental readings that introduce and explain these topics may be beneficial to these students. Another potential solution could be taking a "think, pair, share" [110] approach to reflect on the topic, discuss the topic with another classmate, and share their understanding of the topic with the class.

A number of the concerns expressed by the students included the homework/reading assignments. A major concern with the homework was the amount of research students felt they needed to complete for assignments. Of these concerns, finding sources and then evaluating the quality of the data were prominent concerns. The instructor did suggest a library visit, which may have alleviated some of the difficulties of locating sources, but formal instruction on evaluating sources was lacking from the course instruction. The concerns about reading assignments might be more general to *engineering* courses rather than a university-wide challenge. The longest supplemental reading is approximately 40 pages in length, but all of the readings include graphics and tables which fill considerable space. These students might be accustomed to reading or skimming engineering textbooks and have had preconceptions about the type of reading required for a technical course.

4.1.3: Technology

Another general teaching issue relates to the use of technology in the classroom. The students felt the SimaPro software was too complex for use in the course. Even though the instructor assigned sections of the tutorial as homework and dedicated class time to showing students how to navigate through the software, students still indicated on the post-course survey that the software as a major hurdle to completing the project.

4.1.4: Clarity of Outcomes

The confusion about the course outline/learning objectives is somewhat puzzling. For nearly every PowerPoint presentation the instructor prepared, he included a diagram of either the phases of the life cycle or the steps to complete a LCA. In this diagram, the topic for the class period was highlighted, and the instructor verbalized how the topic fit into LCA. Learning objectives were not so markedly indicated; an improvement of reminding students of the course learning objectives, either by mentioning the syllabus or including learning objectives on homework assignments, could help students connect lecture, discussion, and assignments to the course outline.

4.2: Challenges Unique to the Interdisciplinary Nature of the Course

The challenges associated specifically with the interdisciplinary nature of the course fall into two broad categories: 1) structural challenges stemming from scheduling and location, and 2) egocentric challenges stemming from the students' inability to connect green engineering to their own major ("relatedness") and to see their own major as one integrated component of green engineering ("perspective").

4.2.1: Structural Issues: Team Organization

Part of the challenge of any multi- or interdisciplinary collaboration is structural: the participants generally have different home "locations" and different work schedules that create conflicts when organizing group projects. In this case, each of the disciplines are located in the same general area of campus, but housed in separate buildings; each building is at least 30 yards from its closest neighbor. Since in-major courses are typically held within the same building as the department, students from different disciplines typically do not pass each other during the normal school day. Moreover, the schedule of required classes varied from major to major and year to year; for example ME senior design projects are held Tuesdays and Thursdays for an hour and fifteen minutes with beginning meeting times ranging from 9:30am to 5:00pm. For ISE students, just a recitation is scheduled on Tuesdays and Thursdays from 3:30 to 4:45 pm. When looking outside of engineering, Industrial Design and Architecture students, of all academic levels, have "studio" every Monday, Wednesday, and Friday between 1:00 and 5:00pm; students receive 6 or 7 credits depending on their academic level.

As the course progressed and the students were placed into groups, the students encountered the challenges of managing and working on an interdisciplinary team. The number one challenge the students associated with the project was the difficulty in scheduling group meetings with all team members. While the students did not specifically mention what types of scheduling conflicts they encountered (academic, personal, or job-related) conflicting academic/course schedules is a concern. The scheduling conflicts were amplified by the number of students in each group, and students commented that the group size was an issue.

In addition, when working on the interdisciplinary teams, students felt they had to rely on each other more than they were accustomed to for in-major projects. This point of view could be linked to the approach the students had towards division of labor. Students mentioned benefits of working with members of different disciplines as "a simple way to break up the work" along disciplinary expertise and skill sets. This style of division of labor also might influence the difficulties students associated with compiling the work into the final document for submitting.

These challenges became particularly apparent in students' response to questions 11-14 in the post-course survey and in the interviews. Sample comments addressing this issue include:

- "[T]he effort of trying to coordinate the group aspect of the project takes away from the academic aspect of it"
- "[H]ard to make a coherent project without constantly being in contact with one another"
- "Interdisciplinary teams are hard to work with as seniors because all different majors' schedules are hard to coordinate"

- “[T]he group dynamic is always the same. This is not a phenomenon unique to engineering either… this is just how group work seems to go”

As these comments suggest, the students in this course faced the same organizational challenges seen in other multi- and interdisciplinary projects.

4.2.1.1 Pedagogical Response

In responding to this challenge, faculty need to first evaluate the need for group projects in interdisciplinary courses, second, teach students teaming skills, and third, create sufficient learning spaces to facilitate collaboration. Teaming skills include effective communication, decision-making, and conflict resolution skills. Strategies for creating learning spaces include: providing face-to-face time during class, creating digital workplaces, and providing instruction for appropriate behavior in such arenas [116-120].

4.2.2: Disciplinary Egocentrism

A larger cognitive challenge the instructor faced may be labeled as the disciplinary egocentrism that students bring into an interdisciplinary classroom. An important factor of disciplinary egocentrism is the issue of motivation. Motivation for enrolling in the course can vary from extrinsic motivating factors, such as fulfilling a requirement, to intrinsic motivating factors, for example, gaining a different perspective of engineering. Students with stronger extrinsic motivation might want more examples as to how the interdisciplinary subject will benefit their discipline, an issue of “relatedness.” Conversely, the students expressing intrinsic motivating factors may want to “see the big picture” by gaining a new “perspective.” These predispositions are the extremes of a continuum of disciplinary egocentrism, with the likelihood that an interdisciplinary classroom contains students from many different levels of the disciplinary egocentrism continuum.

4.2.2.1 Relatedness

Throughout the engineering curriculum, students are trained to become professionals in their discipline. Beyond the core curriculum requirements, every course in the sequence directly pertains to the student’s major. Faculty members teaching these courses do not have to exert extra effort to “convince” the students that the content and skills they will gain from a particular in-major course will apply directly to their professional careers.

In contrast, in an interdisciplinary classroom, each student representing a different discipline may not see how the content relates to their specific discipline, career goals, etc. New content not covered in-major might not have apparent connections to prior knowledge the students have. Additionally, students may want specific examples of how the content and skills being taught will advance their professional career. A common issue of relatedness in engineering disciplines is the introduction of communication skills (reading, writing, and presenting) into engineering courses.

The challenges of relatedness were apparent in students’ concerns with connecting Green Engineering to their specific discipline. Some of these examples include:

- Comments about biological materials and material properties being “vague” or not emphasized
- Wanting more examples from student’s discipline
- Wanting examples of how LCA is used in industry, “the real world”
- Only seeing “parts of LCA [as] useful”

- Product design not the focus of student's discipline
- Does not believe content is applicable in major/career: "I'm not sure how relevant the knowledge will actually hold in my career"
- Content not covered in student's major: "Most other classes focus on other measures such as timelines, cost, or ergonomics" and "[Other classes] focus only on manufacturing costs and efficiency"

From these sample comments, students either want the instructor to make connections between Green Engineering and their discipline or begin to see the gaps in their discipline through exposure to Green Engineering. This connection is represented in Figure 23.

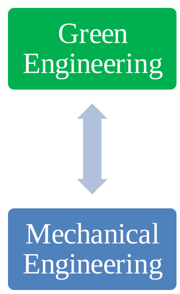

Figure 23: Representation of "relatedness"

4.2.2.2 Pedagogical Response to Relatedness

Faculty members can respond to this challenge by providing examples from a variety of disciplines, specifically the disciplines of the students enrolled in that particular semester; students could also be assigned homework assignments related to their major, with faculty directing students to appropriate sources. Additionally, faculty can have students reflect on the concepts introduced in the interdisciplinary course with respect to their prior knowledge from in-major courses; here the faculty members may need to help students indentify where certain content fills gaps in their prior knowledge.

4.2.2.3 Perspective

A final challenge faced by both faculty and students is one of perspective. The challenge for faculty is trying to guide students into seeing how their specific discipline intersects the interdisciplinary subject and connects to the other disciplines. Students must overcome disciplinary egocentrism in order to see the "big picture" of how all the disciplines interrelate with the interdisciplinary topic and each other.

Using Green Engineering as an example, mechanical engineers need to become aware of the connections between Mechanical Engineering, Green Engineering, and other fields. Figure 24 illustrates a simplified representation of the connectedness of Green Engineering, Mechanical Engineering, Social Sciences, and society.

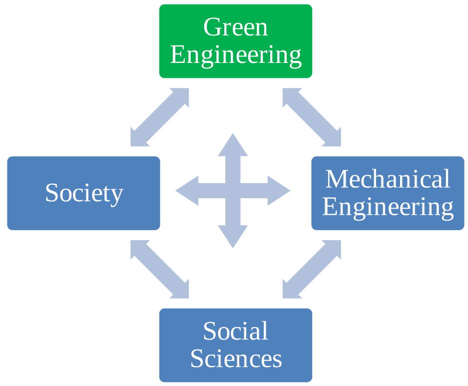

Figure 24: Representation of "perspective"

Since students are typically educated within their major, some students within an interdisciplinary classroom might not realize different perspectives of and approaches to a problem. Some of the students indicated they enrolled to "gain a different perspective of engineer;" these students probably believed they only would gain the perspective of green engineers rather than the perspectives of the other disciplines represented by their fellow classmates. Yet this broad perspective is precisely what interdisciplinary courses can provide, as the data shows.

Through the team project, students mentioned the perspective, knowledge, skills, and experiences of their fellow classmates:

- Different analysis/viewpoints can lead to different outcomes
- Gaining depth of perspective of everything involved in design process, including environmental constraints to the list of design constraints from in-major classes/experiences
- Introduced to new databases (sources of information)
- How weighting is different for "different groups/people"
- Gaining "green" perspective
- Different approaches/evaluation methods/viewpoints from other disciplines (seen in teamwork): "they attack problems differently"

Most of these comments show students starting to overcome disciplinary egocentrism through the exposure to students from different disciplines.

4.2.2.4 Pedagogical Response to Perspective

Even if an instructor decides a group project is not appropriate for an interdisciplinary course, having students form base groups, a group of students providing support and clarification for each other throughout a semester or year [98] (pg. 437), can provide faculty with a chance to pair students of different disciplines to discuss the interrelatedness of those disciplines with the interdisciplinary subject. Another method of grouping students of different disciplines is by using a jigsaw technique [98] (pg. 439). In the jigsaw method, each student is given a part of the information; then, each student teaches the rest of the group the information. In a course such as the LCA course in this case study, each of four students could be given a phase of the life cycle to research aligning with his/her discipline. When these students meet to discuss the phases of the life cycle, students from should begin to see how those four disciplines "fit" in Green Engineering and compliment each other.

Chapter 5: Conclusion

5.1: Challenges Unique to Interdisciplinary Courses

From examining this case study of Environmental Life Cycle Analysis and Materials Selection, the researcher indentified several challenges the faculty member faced in the classroom. While many of the challenges are generic to any classroom experience, two unique challenges of interdisciplinary classrooms emerged from the data. The unique challenges of interdisciplinary classrooms are 1) the structural issues related with organizing students from different disciplines with conflicting schedules, and 2) disciplinary egocentrism of students through their education and training from in-major courses.

5.2: Pedagogical Strategies to Overcome these Unique Challenges

In response to the challenges of teaching an interdisciplinary course, several current pedagogical strategies can help faculty members begin to overcome these challenges. For these unique challenges, some strategies include:

- Team Organization
    - Evaluate the need for group project
    - Teach teaming skills: communication, decision-making, conflict resolution
    - Create shared learning spaces for teams: face-to-face and/or digital workplaces
- Relatedness
    - Provide examples from all disciplines
    - Assign homework related to students' majors
    - Engage students in reflection exercises
- Perspective
    - Form base groups
    - Use jigsaw techniques when creating and assigning homework/projects

While these strategies may help alleviate the challenges indentified in this thesis, scholars have the potential to create new pedagogies specifically for interdisciplinary classrooms.

5.3: Interdisciplinary Learning Objectives

Since the review of current ASEE conference papers showed a deficiency of learning objectives for interdisciplinary learning and collaboration, sample interdisciplinary learning objective for the unique challenges include:

- Team organization

    - Students shall be able to demonstration project management skills by organizing and planning team meetings, both face-to-face and virtual.
- Relatedness
    - Students will be able to compare/contrast the knowledge and techniques of the interdisciplinary topic with their major.
- Perspective
    - Students will be able to compare/contrast the knowledge and techniques of their major with the other disciplines represented in the classroom.
    - Students will be able to analyze a problem from multiple disciplinary perspectives.

5.4: Future Research Questions

This section summarizes the research questions raised through the literature and the case study. These questions center on interdisciplinarity, disciplinary egocentrism, and assessment.

- How do we train students to become a professional within a discipline without creating disciplinary egocentrism?
- How did the interdisciplinary nature of the classroom affect the general challenges of teaching any course?
- What pedagogies are more effective in interdisciplinary courses?
- What are the key elements of an interdisciplinary pedagogy?
- How do we train students to become interdisciplinary?
- What are measures of interdisciplinarity in the context of an interdisciplinary course rather than in an interdisciplinary team?
- Do we want to measure gains in new content knowledge of students from all disciplines involved?
- How do you measure students cognitively blending/integrating two or more disciplines?
- Do you expect to see a shift in thinking, decision making, and/or problem solving?
- Are you trying to judge a shift or awareness in perspective?
- Is simply being able to communicate across disciplinary boundaries the desired outcome of interdisciplinarity?

While all of these questions are important to advance the current understanding of interdisciplinary learning and collaboration, the researcher plans to continue following the thread of disciplinary egocentrism. A future study will focus on design thinking and how different disciplines approach qualitative constraints, specifically in design.

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63. Baier, R. and Y. Tao. *An Interdisciplinary Pedagogical Teaching Approach for Engineering, in Conjunction with Architecture and Construction with Solar Decathlon Project*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
64. Bualuan, R., et al. *Project G: Multidisciplinary Teamwork Design at its Best*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
65. Cezeaux, J., et al. *Design for the Disabled as an Interdisciplinary Laboratory Project*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
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72. Parten, M. and T. Maxwell. *Monitoring and Control in Advanced Vehicle Engineering Laboratories*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
73. Shahnasser, H. and C. Pong. *Interdisciplinary Engineering Design Projects to Enhance the Research Experience for Undergraduates*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
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78. Bucks, G., et al. *Facilitating Multidisciplinary Teams in a Service-Learning Environment*. in *2007 ASEE Annual Conference & Exposition: Riding the Wave to Excellence in Engineering Education*. 2007. Honolulu, Hawaii.
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111. Ott, L. and M. Longnecker, *An Introduction to Statistical Methods and Data Analysis*. Fifth Edition ed. 2001: Duxbury Press.
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Appendix A: Course Syllabus

[text removed] – Environmental Life Cycle Analysis And Materials Selection

Notes and Syllabus (Spring [text removed])

Time and Place: [text removed]

Instructor: [text removed]

Office Hours: [text removed]

Course Learning Objectives:

Having successfully completed this course, the student will be able to:

1. Describe the 4 phases of the life cycle of a product, process, or system
2. Describe the 4 steps for completing a life cycle analysis
3. Define and select appropriate functional units for LCA Analyses
4. Discuss causes/effects of commonly used environmental impact LCA categories
5. Compare the concepts of environmental impact midpoints and endpoints
6. Explain characterization factors in LCA for impact analysis
7. Explain the concept of "weighting" in LCA analysis and interpretation
8. Discuss why design decisions dominate environmental impacts of products and processes
9. Explain why materials selection is a critical design parameter for LCA
10. Find sources of environmental impact data and assess the quality of that data
11. Explain the strengths and weaknesses of Streamlined LCA compared to full LCA
12. Discuss several limitations of LCA
13. Discuss the connection of Life Cycle Analysis (LCA) to technology, economics, society, the environment, and political decisions.
14. Create a simple stream-lined LCA for a product, process or system
15. Create a simple LCA on a product, process, or system using a spreadsheet or commercial software

Required "Text": And Software

There is no single text which adequately covers the range of material for this course. Therefore, various articles, book chapters, etc. will be provided throughout the course As much as possible, these will be provided on-line to minimize paper use.

The following software package will be used in the course. A nominal fee will be charged for the temporary license for this software.
- *SimaPro 7 LCA Software*, Educational version, Pré Consultants, 2006.

Grading:

In class exercises	5 %
Quizzes (5 – throw out 1)	20 %
Homework (approximately 10)	50 %
Major Project	25 %
	100 %

Related: **References**

The following books have good content related to the topics of this class. Each is focused on a specific topic. The first three are standard textbooks with a focus on current methods while the next two are not as well developed for use as a text, but excellent forward-thinking works which are highly recommended for general reading. The final book listed is an excellent introduction to the concept of environmental ethics.

- *Industrial Ecology, 2nd Edition*, T. Graedel and B. Allenby, Prentice Hall, 2003.

- *Materials Selection in Mechanical Design, 3rd Edition*, M. Ashby, Elsevier, 2005.
- *Green Engineering – Environmentally Conscious Design of Chemical Processes*, D. Allen and D. Shonnard, Prentice Hall, 2002.
- *Natural Capitalism – Creating the Next Industrial Revolution*, P. Hawken, A. Lovins, and L. H. Lovins, Back Bay Book, 2000.
- *Cradle to Cradle – Remaking the Way We Make Things*, W. McDonough and M. Braungardt, North Point Press, 2002.
- *Engineering, Ethics, and the Environment*, P. Vesilind and A. Gunn, Cambridge University Press, 1998.

Instructional Notes:

Instruction will include classroom lectures, discussions, assigned homework, and a team project:

1) Blackboard and email will be utilized frequently for assignments, lectures, information, lecture notes, etc. If you miss a class, consult your classmates or Blackboard for information. I will generally not have time to respond individually to email questions which have been covered in class or been posted in BlackBoard.
2) **THE RULES OF THE [text removed] HONOR CODE APPLY TO ALL ASPECTS OF THIS COURSE.** You are responsible for knowing its provisions ([hyperlink removed]). If you have any questions regarding how this code specifically applies to assignments in this class, please contact me.
3) Homework is due at class on the due date in paper form. Late work will be penalized 10% per day until the solutions are posted. Exceptions may be possible if the instructor is contacted <u>in advance</u>.
4) Unannounced quizzes are a distinct possibility at any time. They will be used to assess how well lecture and reading material is being assimilated. One quiz can be dropped. Quizzes can be made up only if you contact the instructor <u>prior</u> to class regarding your absence.
5) In some cases, lectures will consist of material not covered in the readings so class attendance and participation are important for success in this class. Please be prepared for each class by reading and studying the assigned material prior to coming to class.
6) If you need adaptations or accommodations because of a disability (learning disability, attention deficit disorder, psychological, physical, etc.), if you have emergency medical information to share, or if you need special arrangements in case the building must be evacuated, please make an appointment with me as soon as possible

[text removed] Topics* **Spring Semester, [text removed]**

I. *Introduction*
  A. Product Life Cycle
  B. Life Cycle Analysis
  C. Environmental Impacts

II. *Product Life Cycle, Materials Selection and Design*
  A. Extraction and Production Energy
  B. Manufacturing/Processing and
  C. Mass Balances
  D. Packaging
  E. Transportation/Distribution
  F. Use
  G. End-of-Life/Recycling/Landfill/Incineration
  H. Materials Selection
  I. Product Design
  J. Process Design
  K. Design for Environment

III. *Life Cycle Analysis*
  A. Life Cycle Analysis Framework
  B. Life Cycle methods and software
  C. Inventory Analysis
  D. Impact Assessment
  E. Data location and integrity
  F. Sensitivity Analysis
  G. LCA interpretation
  H. LCA Weighting
  I. LCA Limitations
  J. Life Cycle Cost Analysis
  K. Project Presentations

***Note - this outline is a general roadmap of the topics that we plan to cover in this course. The actual path taken and time spent on these topics will vary as we work our way through them.**

Appendix B: List of Additional Readings

Ashby, M.F., et al., *The CES Eco Selector - Background Reading*. 2 ed. 2004: Granta Design, Cambridge.

Chapter 1: Mining Overview, in *Energy and Environmental Profile of the U.S. Mining Industry*. 2002, Prepared by BCS, Incorporated for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy: http://www1.eere.energy.gov/industry/mining/pdfs/overview.pdf.

Graedel, T.E. and B.R. Allenby, *Chapter 5: The Status of Resources*, in *Industrial Ecology 2nd*. 2003, Prentice Hall: Upper Saddle River, New Jersey. p. 55-67.

Graedel, T.E. and B.R. Allenby, *Chapter 11: Designing for Energy Efficiency*, in *Industrial Ecology 2nd*. 2003, Prentice Hall: Upper Saddle River, New Jersey. p. 137-148.

LCAccess - LCA 101. 2001, U.S. Environmental Protection Agency and Science Applications International Corporation: Retrieved from http://www.epa.gov/ORD/NRMRL/lcacess/lca101.htm.

Life cycle analysis and assessment: Retrieved 2/6/2007 from http://www.gdrc.org/uem/lca/life-cycle.html.

Wagner, L.A., *Materials in the Economy: Material Flows, Scarcity, and the Environment*. 2002: US Dept. of the Interior, US Geological Survey.

Trautmann, N.M., K.S. Porter, and R.J. Wagenet, *Modern Agriculture: Its Effects on the Environment*. 1985: http://hdl.handle.net/1813/3909.

Why Take A Life Cycle Approach? 2004, United Nations Environment Programme, United Nations Publications: http://www.unep.fr/pc/sustain/reports/lcini/UNEPBooklet.ENGprint.pdf.

Appendix C: Homework Assignment #1

Assignment:

Based on your current understanding of environmentally-conscious products, select a product available in the marketplace today which has enough environmental benefits for you to consider it "green" compared to other products which provide similar function. Write a short memo (1 – 2 pages) describing this product and clearly stating the specific features which make it a green choice.

Your memo will be graded on coverage of the following items:

1. A brief introduction to the product and its intended function. Comment on any major materials or energy required to manufacture, market, and use this product (**10 points**).

2. Brief comments on the specific life cycle phase(s) and the environmental issues for which the product has reduced environmental impact when compared with other similar products. Provide simple data or analysis to quantify the environmental benefits (**10 points**).

3. Characteristics of the product which still have adverse environmental impacts and which provide opportunities to improve the product even further from an environmental perspective (**10 points**).

4. Comments on why or why not this product might be attractive to consumers (**10 points**).

Use the template provided below for your memo with 1 inch margins and Tahoma size 10 font. The memo will be graded on the quality and clarity of the comments in the areas mentioned above. References should be cited where appropriate. Some example product categories and possible websites are listed below if you are having trouble choosing a product or finding information about it.

Examples of Product Categories:
Automobiles
Building and Household Products
Organic food or materials
Fuels (ethanol, biodiesel)
Energy generation (wind, solar, nuclear)
Cleaning products
Energy Star Appliances and Electronics

Web Sites for Product Information:
http://www.greenhome.com/
http://www.seventhgeneration.com/our_products/
http://www.ecomall.com/
http://www.greenbuildingsupply.com//Public/Home/index.cfm
http://www.gaiam.com/retail/gai_shophome.asp
http://www.environmentalhomecenter.com/shop.mv

Green Product Homework Memo

To: [Professor]
From:
Date:
Subject: Acme Green Widgets

This memo described the environmental advantages of Acme Green Widgets compared with other widgets currently available in the marketplace……….

Appendix D: Homework Assignment #2

Assignment:

1) In this assignment you will research and report on the first phase of the life cycle, the extraction phase, for the material you selected. A list of students and assigned materials is attached at the end. You should consider the following aspects for your material:

   a) Where geographically does the material come from? Are there geographic limits to where the material can be obtained or extracted? (**5 points**)
   b) In what form is the material when extracted? How concentrated or pure is the material when extracted? (Do not discuss purification or secondary processing in detail for this homework – this will be done later) (**5 points**)
   c) How is the material physically extracted or obtained from the natural world? (**5 points**)
   d) How energy-intensive is the extraction process? If possible provide quantifiable data; if data is not available, explain briefly which extraction steps will require significant amounts of energy? (**5 points**)
   e) Describe the main potential environmental and/or health impacts associated with extraction of the material (main categories and potential midpoints or endpoints) (**5 points**)
   f) Comment on the estimated reserves, usage rate, and uncertainties in this data for nonrenewable resources. If the material is renewable, discuss renewal rates, land requirements and yields, and other related issues. From this data, include simple calculations which estimate both the most and least optimistic **depletion times** for your material from reserve and usage data. Include the data, the source of the data (CES, USDA, Lumber industry, etc) and a brief discussion of any key assumptions that were necessary. For some materials, usage or reserves assumptions will be necessary. For renewable resources, instead of depletion time estimate the maximum and minimum **land area** necessary to meet current usage based on yield per acre, for example. (**10 points**)

If your material has more than one main chemical or material component as is the case for alloys, composites, and some polymers, discuss the issues above for each of the main components (examples: for alloys like brass consider both metal elements in the discussion; for polymers like PVC or PTFE, consider the chlorine or fluorine in addition to the back polymer which give the material different properties).

Provide this information in the form of a corporate memo (see template), not just a list of answers to the questions above. Assume the instructor is your boss at a product design and engineering company and has requested a memo regarding potential extraction issues for your material if it is selected for use in a new product or process.

This memo should be typed and no more than 3 pages long (single spacing, 1 inch margins, font type no smaller than 10 and no larger than 12 point) **-** deductions will be made for memos longer than 3 pages. Be concise, but complete. Consider this a professional memo – deductions will be taken for spelling errors, poor grammar/syntax, inadequate references, readability, etc. (**5 points**). Grading will focus on coverage of all relevant items and the quality of this content. Deductions will be made for major issues with your material which are not mentioned (for example – severe geographic limitations, significant health issues, major environmental problems, etc.).
(**40 points total**)
If you have any questions regarding your specific material, or feel compelled to change your material after considering this homework, please contact the instructor as soon as possible.

Materials Assignment List

Name	Material Selection
(names removed)	Leather
	Lithium
	Glass
	Carbon Fiber
	Trex
	Biodiesel
	Uranium
	Chromium
	Diamond
	Polyvinylchloride
	Hemp
	Nylon (Polyamide)
	Elastic
	Rubber
	Cotton
	Coal
	Brass
	Silk
	Lumber
	Copper
	Carbon Fiber (PAN)
	Concrete
	Aluminum
	Titanium
	Plywood
	Gallium
	Bamboo
	Polystyrene
	Steel
	Paper
	Polyethylene

Green Design and Engineering Corporation

Internal Memo

To: [Professor]
From:
Date:
Subject: Extraction phase life cycle issues for (*your material here*)

This memo summarizes the primary life cycle environmental issues for the extraction phase for (*your material here*)………………….

Appendix E: Homework Assignment #3

Assignment: In this assignment you will research and report on the second phase of the life cycle, the manufacturing phase, for your material.

1) To do this, pick a specific product which uses your material as a key input. Explain briefly, but clearly, the function of the product and any relevant details. (Note - simple products will be easier to handle than complex products)

Then, also comment on the following aspects for your material and product:

g) Draw a simple process flow diagram with major steps and briefly describe the manufacturing processes used to turn your raw material into both a usable material and then the final product. Depending upon your material, this might include purification, separation, chemical reaction, etc. to refine the raw material as well as secondary processes like molding, casting, shaping, etc. to form the final product. (**10 points**)

h) Mention the major inputs of energy, water, chemicals, etc. necessary for the manufacturing process. Try to quantify at some level the amounts of these inputs per some unit of your product. State any necessary assumptions. (**10 points**)

i) Mention the major outputs in addition to the product such as co-products, air emissions, liquid waste, solid waste, etc. Try to quantify the amounts of these inputs per some unit of your product. State any necessary assumptions. (**5 points**)

j) Comment on why your material is used for this product in terms of the product functional requirements and your materials' physical properties. (**5 points**)

k) Describe any significant health or environmental impacts that may be associated with the manufacturing processes needed to make your product. (**5 points**)

l) Select at least one other material that could also be used for your product which is a better environmental choice based on some criterion of your choosing.
   - Explain briefly how this material might be better for the environment
   - Give one reason that this material might not be currently used for this product or is used infrequently. If you cannot find any materials which seem better from an environmental perspective (this will be the case for some of your materials), then suggest one possible change in the process from extraction through manufacturing which would benefit the environment in some way. Explain the potential environmental benefit briefly. (**10 points**)

Provide this information in the form of a corporate memo like in Homework 2. Again assume the instructor is your bosses at a product design and engineering company and has requested a memo regarding the manufacturing issues involved for your material and product. Consider this a professional memo – deductions will be taken for spelling errors, poor grammar/syntax, inadequate references, readability, etc. (**5 points**). This memo should be typed and no more than 3 pages long (single spacing, 1 inch margins, font type no smaller than 10 and no larger than 12 point). Grading will focus on coverage of all relevant items above and the quality of this content. Deductions will be made for major material, processing, or product issues which are not mentioned, for poorly written memos, or for poor references. References should be noted using numbers at the point where they are used in the text, and then listed by number at the end of the memo. (**50 points**)

Appendix F: Homework Assignment #4

1. Using the NREL database (*http://www.nrel.gov/lci/*) and the streamlined data for "*Cotton Production*" under the category "**Agricultural Products**" information in the Database section, answer the following for 100 kg cotton as a functional unit (**20 points**):

   NOTE CAREFULLY THE UNITS REQUESTED. IN SOME CASES, YOU WILL NEED TO LOOK UP AND MAKE UNIT CONVERSIONS.

   a) What is the diesel fuel input for farm tractors in gallons (**2 points**)?

   b) What is electricity input in kWh (**2 points)**?

   c) What is the nitrogen fertilizer input in pounds (**2 points)**?

   d) How much 2, 4 – D is output to both air and water in kg (**2 points)**?

   e) How much Malathion is output to both the air and water in kg (**2 points)**?

   f) From other references, briefly explain what 2, 4-D and Malathion are used for in cotton production and give a potential environmental impact for each. List your references. (**4 points)**?

   g) How much land, in acres, is required to grow this amount of cotton (**2 points)**?

   h) Regarding land use, what is the ratio of conservation tillage vs. conventional tillage for this inventory? Briefly describe the main differences between these methods of tillage and provide several advantages and disadvantages for conservation tillage (**4 points)**:

2. Use the SimaPro tutorial and databases to answer the following questions (**20 points**):

   a) Coffee Pot (Lesson 1)

   i) What is the functional unit for the Coffee Pot in the Introduction to SimaPro Project (**2 points)**?

   ii) For the Assembly Model Sima (Plastic), what is the highest impact category in the Eco-Indicator 99 (H) method under either "Normalization" or "Weighting" in Analzye (**2 points)**?

   iii) For the Assembly Model Sima (Plastic), if you generate the process network and set the Cut-off at 5%, how many nodes are visible (**2 points)**?

   iv) For the Assembly Model Pro (Aluminum), if you Analyze and look at Characterization, which of the materials/subassemblies dominates in all impact categories (**2 points)**?

   v) If you compare the Life Cycle Sima (Plastic), Life Cycle Pro (no takeback), and Life Cycle Pro (with takeback), what are Single Score values for each when analyzed (**2 points)**?

b) Wood Shed (Lesson 2)

i) Explain the difference between a “Waste Treatment” and a “Waste Scenario” in SimaPro (**2 points)**?

ii) What is the difference between a “Product Stage” and “Processes” in SimaPro (**2 points)**?

iii) For the complete Simple Shed Life Cycle, with the Eco-Indicator 99 (H) method as the default, what are the two highest categories when this life cycle is analyzed and the data plotted using the “Weighting” tab (**2 points)**?

iv) Change the method to CML2 baseline 2000, with World 1995 as the Normalization set. Analyzing with this method and looking under the “Normalization” tab, now what are the two highest categories for this life cycle (**2 points)**?

v) When you set the cut-off to 0.0 for the entire life cycle to view the entire process network, what is the one contribution to this process which has a negative environmental load (benefit)? Explain why this is a benefit according to what you entered in the tutorial to define this process (**2 points)**?

Appendix G: Homework Assignment #5

1. For the three LCA comparisons listed below, provide the following (**24 points**):
   a) An appropriate functional unit for comparison and a brief explanation for this choice (**2 points**)
   b) A one or two sentence scope statement defining the LCA comparison and some boundaries (**2 points**)
   c) List 4 necessary pieces of data/assumptions required make the LCA comparison (**4 points**)

   LCA Comparisons
   - Electric vs. manual shaving
   - Hand drying using an electric forced air blower vs. paper towels
   - Aluminum vs. glass beverage containers

Example: Automobile vs. Bus for commuting to work

a. **Functional unit**: per 100,000 (passenger * miles) traveled by car and by bus. To account for different fuel economy and passengers carried, both these factors need to be in the functional unit for a fair comparison.
b. **Scope Statement**: This LCA will compare the environmental impact of providing 100,000 passenger miles of travel by car vs. by bus. This LCA will focus on the use phase of the vehicles only since this phase is expected to dominate the life cycle.
c. **Necessary data**:
   i. Fuel economy for each vehicle
   ii. Fuel type/engine for each vehicle and associated emissions
   iii. Maintenance required per 100,000 miles for each vehicle
   iv. Number of passengers carried per 100,000 for each vehicle

2. Use the Carnegie Mellon Input Output web-based model (EIO-LCA) and the TRACI data to answer the following questions: (**15 points**)

   1. For $1 million dollars of economic activity, compare the following:
      a. Agriculture, Livestock, Forestry, Fisheries – "Cattle Ranching and Farming"
      b. Agriculture, Livestock, Forestry, Fisheries – "Grain Farming"

      i. Compare the total outputs for "Energy" and "Greenhouse Gases" for each of these sectors and the total air releases under "Toxic Releases" (**3 points**):

      ii. Under the "Toxic Releases" data category for each sector, use the "*Click to see TRI results with detail by chemical in a new window*" option to fill out the second and third columns of the following table (**2 points**):

	Toxic Release Data Total Air Releases		**TRACI – Characterization Factors**	
Chemical	**Cattle Ranching (kg)**	**Grain Farming (kg)**	**Ecotoxicity –Air (kg 2, 4 - D equiv./kg)**	**Smog - Air (kg NOx equiv./kg)**
Ammonia				
N-Hexane				
Toluene				
Methanol				

      iii. Use the TRACI impact characterization factors from the Excel sheet posted in Blackboard or SimarPro TRACI Method to enter the characterization factors for the "Ecotoxicity – air" and

"Smog" impact categories. Assume that "Hexane" and "N-Hexane" are the same chemical (**2 points**)

iv. Based on these 4 chemicals, determine the overall impact indicator values using the data in the table above for the two agriculture sector and two impact categories. The final results should go in the table below, but show the calculations used to obtain these values. (Note these aren't the total impact indicators since we are only summing 4 of the outputs) (**4 points**)

	Impact Indicators (TRACI method)	
Sector	**Ecotoxicity –Air (kg 2, 4 - D equiv.)**	**Smog - Air (kg NOx equiv.)**
Cattle Ranching		
Grain Farming		

v. Provide one reason that the functional unit of dollars ($) which is always used for Economic Input-Output analysis may be a poor choice for this comparison. (**2 points**)

vi. Suggest an alternative functional unit which may be a better choice for comparison of "cattle ranching" to "grain production" and explain briefly why. (**2 points**)

3. Consider the following data from Dr. McGinnis' household energy use in 2006 to answer the questions below (**18 points**):

- Automobile (gasoline) – 15,000 miles driven, average fuel economy = 25 mpg
- Electricity – household electricity including air conditioning/heat pump = 12,000 kWh
- Natural Gas – hot water heater, dryer, and boiler furnace = 400 therms

a. Convert each type of fuel use into a common unit – megajoules (MJ) and determine the percentage energy use by for each fuel. State your assumptions and data references. (**6 points**)

b. Estimate the emissions of CO_2 for use of these fuel amounts. Again state your assumptions and references. For electricity specifically, provide the assumptions made regarding the fuel mix (coal, natural gas, nuclear, hydropower, etc.) for electricity generation and CO_2 emissions. (**6 points**)

c. If Dr. McGinnis wants to reduce his overall household CO_2 footprint, provide one suggestion for the reduction of fuel use and CO_2 emissions. Estimate how much CO_2 will be reduced annually with your proposed change and calculate the cost effectiveness ($/kg CO_2 reduction). State all assumptions in these estimates. For any suggestions regarding new equipment purchases you can assume the current household equipment is of average efficiency.(**6 points**)

Various US Department of Energy websites as well as some of the SimaPro methods are potential sources of data.

Appendix H: Homework Assignment #6

Assignment: In this assignment you will research and report on the last 2 phases of the life cycle, use and end-of-life, for your material and product.

Consider the energy and environmental impacts for the use and end-of-life phases for your material and specific product. Some of you have materials/products with no significant use phase or disposal phase – you should explain this explicitly in your memo. Comment on the phase, or phases, that are relevant to your topic using the questions below as a guide. If you are unsure of whether you product has either of these phases, ask rather than assume that you can ignore a phase.

<u>Use Phase (if relevant):</u>

m) What energy, water, consumables, etc. are required as inputs for the use of your product? For example, automobile require gasoline, oil, tires, etc. for use). Provide quantitative data or estimates based on some functional unit and time frame. (**10 points**)

n) What outputs result from use of your product and what are the potential environmental/health impacts? Provide quantitative data or estimates based on some functional unit and time frame. (**10 points**)

o) Suggest at least one change in your product's design, or a process or policy change that could improve the environmental performance of the use phase for your product. (**10 points**)

p) Provide quantitative data or estimates on the reduced environmental impact due to this change. (**10 points**)

<u>End-of-Life Phase (if relevant):</u>

a) What are the potential end-of-life scenarios for your product and/or material? (**5 points**)

b) How much of your product is typically reused, recycled, down-cycled, land filled, incinerated, or composted? Provide quantitative data or an estimate of what percentage of your product goes to the various end-of-life options. (**10 points**)

c) If your product/material can be recycled or down-cycled, estimate the energy and raw materials savings compared with using virgin material. If your product is down-cycled, mention what properties are degraded and what kinds of products can be made with the down-cycled material. If your product can be incinerated, estimate the amount of energy recoverable. OR…. If your product/material is not typically reused, recycled, or down-cycled, comment on why this is the case. For example, is it a materials issue, a product design issue, a cost issue, a consumer behavior issue, a policy issue, or is there another reason? (**5 points**)

d) Comment on any potential environmental or health issues associated with the disposal or end-of-life or your product? (**10 points**)

e) Suggest at least one change in your product's design, or a process or policy change that could improve the environmental performance of the end-of-life phase for your product. (**10 points**)

Provide this information in the form of a corporate memo similar to previous homeworks. Again assume the instructor is your boss at a product design and engineering company and has requested a memo regarding the use and disposal issues involved for your material and product. This memo should be typed and no more than 3 pages long (single spacing, 1 inch margins, font type no smaller than 10 and no larger than 12 point). Grading will focus on coverage of all relevant items above and the quality of this content. Deductions will be made for major use or disposal issues which are not mentioned, for poorly written memos, or for poor references. References should be noted using numbers at the point where they are used in the text, and then listed by number at the end of the memo. (**40 points**)

Appendix I: Homework Assignment #7

1. Consider the comparison of two similar products using LCA results in which you have accurate environmental impact factors over a range of categories. Choose the weighting scale that you personally would apply to these impact factors for the environmental impact categories listed in the table below. Ensure that the weighting for all categories sums to 100%. Higher percentages indicate higher importance and categories with the same weight are considered of equal importance. Provide a brief justification (one or two paragraphs) for your weighting based on your knowledge and environmental ethics. There are no "right" answers for this question, so grading will be based on your justification for your relative weights. (**20 points**)

Impact Category	Weight (%)
Global Warming	
Acidification	
Ozone Depletion	
Eutrophication	
Smog Formation	
Human health effects	
Ecosystem health effects	
Depletion of Fuel Resources (Oil, Natural Gas, Coal, etc.)	
Depletion of Mineral Resources	
Solid Waste Disposal (Landfill)	
Total	***100***

Also rate the following combined categories separately and briefly justify:

Impact Category	Weight (%)
Human Health	
Ecosystem Effects	
Resource Depletion	
Total	***100***

2. Conduct a survey of 5 students on campus in which you ask them to weight these impact factors for the environmental impact categories listed in the two tables above. Use increments of 5% or greater and ensure that all categories sum to 100%. Summarize and comment on this data briefly in a short paragraph. (**10 points**)

	Weight (%)				
Impact Category	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**
Global Warming					
Acidification					
Ozone Depletion					
Eutrophication					
Smog Formation					
Human health effects					
Ecosystem health effects					
Depletion of Fuel Resources (Oil, Natural Gas, Coal, etc.)					
Depletion of Mineral Resources					
Solid Waste Disposal (Landfill)					
Total	***100***	***100***	***100***	***100***	***100***

	Weight (%)				
Impact Category	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**
Human Health					
Ecosystem Effects					
Resource Depletion					
Total	***100***	***100***	***100***	***100***	***100***

Appendix J: Homework Assignment #8

This homework requires reading, review and analysis of 4 different types of Life Cycle Analysis reports which are posted in BlackBoard:

- SteelCase Think Chair LCA Summary
- "*How Green Are Green Plastics*" – Scientific American article
- "*1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices*" - Environmental Science and Technology journal article
- Wind Turbine LCA Report

4. Review the SteelCase Think Chair Life Cycle Assessment document posted on BlackBoard to answer the following questions (**12 points**):

    a. What are the 4 Life Cycle Stages assessed for this product?

    b. Why isn't the use phase assessed?

    c. What are the 4 Impact Assessment Categories which are quantified?

    d. Why are quantitative impact values not calculated for the categories "Abiotic Resource Depletion", "Waste", and "Toxic Substances"?

    e. Which Life Cycle stage for this product has the highest contribution to environmental impact in each impact category?

    f. Briefly comment on one strength <u>and</u> one weakness regarding the LCA approach, data, analysis, or interpretation in this document.

5. Review the green plastics article posted on BlackBoard to answer the following questions (**12 points**):

    a. What is PLA, which plastic is it often substituted for, and what kinds of products is it used in?

    b. How much oil does the plastics industry use per year?

    c. What are the main advantages of PLA from an environmental perspective?

    d. What are the main disadvantages of PLA from an environmental perspective?

    e. How does using biomass as an energy source for plastic production improve the environmental impact?

    f. Briefly comment on one strength <u>and</u> one weakness regarding the LCA approach, data, analysis, or interpretation in this article.

6. Review the semiconductor manufacturing article posted on BlackBoard to answer the following questions (**12 points**):

a. What are the 6 Life Cycle Stages assessed in this article with respect to energy requirements? Which phase dominates energy use?

b. List two issues this article mentions regarding data collection and quality?

c. What specific aspect of the fabrication process does this article highlight as being particularly energy intensive? Briefly, why is this the case?

d. Explain why the authors claim that the energy and materials estimates in the article are a "lower bound"?

e. What is the TRI program and what conclusion does this article make regarding it based on the LCA data and analysis?

f. Briefly comment on one strength and one weakness regarding the LCA approach, data, analysis, or interpretation in this article.

7. Review the wind turbine LCA report posted on BlackBoard to answer the following questions (**12 points**):

   a. What is the functional unit for this LCA?

   b. What characterization method is used in this LCA and what are its impact categories?

   c. What are the two largest impact categories for the normalized LCA results of the wind turbine?

   d. What other electricity generation technologies were compared to the wind turbine?

   e. Using the system efficiency data with simple assumptions and calculations, how long does it take for the wind turbine to generate as much energy as is needed as an input over its lifetime?

   f. Briefly comment on one strength and one weakness regarding the LCA approach, data, analysis, or interpretation in this report.

Appendix K: Homework Assignment #9

Assignment:

In this assignment, you will summarize the 4 life cycle phases for your material/product based on the 3 homework memos you have previously submitted.

1. Use the one page fact sheet template provided as a guide to summarize your information, but tailor it appropriately for your material/product. Highlight the areas which are most important for your material/product rather than following the example exactly. Grading will focus on your ability to clearly and concisely summarize the key information for your material. Do not focus on obtaining new material, but rather on summarizing your information well (**20 points**)

2. Briefly review 4 of your classmate's factsheets on BlackBoard and provide the following information (**20 points**):

    a. Which 4 materials/factsheets did you review?

    b. List the two most surprising or interesting things which you learned?

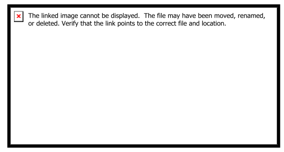
    c. List two specific examples of important data/information which you think would improve any two of the summaries that you reviewed.

    d. After reviewing these fact sheets, list two things you might consider modifying or adding to your factsheet to improve it.

    e. Briefly comment on one potential benefit <u>and</u> one potential problem if these factsheets were made available on the internet for use by students and the general public.

Material: Polycarbonate

Product: Lenses for eyeglasses, sunglasses, and safety glasses

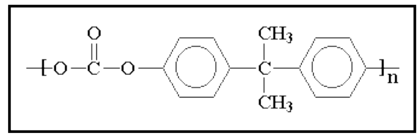


Background:
Polycarbonate was developed in the early 1950's by both General Electric in the US and Bayer in Germany. Known commonly as Lexan®, as well as by various other tradenames, polycarbonate is a thermoplastic polymer widely used in applications where optical transparency and impact resistance are important. It has excellent optical transmission (>85%) across the visible light spectrum (400 – 700 nm), but has relatively low hardness compared with other polymers and therefore is nearly always coated to provide additional scratch resistance for lens applications. Additives to the basic polycarbonate polymer are common to provide specific materials properties for processing or performance.

Select Properties:[1]

Density:	1140 ~ 1210 kg/m^3
Young's Modulus:	2.2 ~ 2.4 GPa
Index of Refraction:	1.60 @ 520 nm
Glass Transition Temperature:	142 ~ 205 ºC
Production Energy:	105 - 116 MJ/kg

Polymer Repeat Unit:



Note that different grades of polycarbonate or additives can significantly alter the materials properties compiled above.

Extraction:
Polycarbonate is chemically formed from reaction between bis-phenol A and phosgene. These chemical precursors are produced from chemical reactions using petroleum-based chemicals so any life cycle analysis of this polymer must consider the environmental impacts of the extraction and refining of crude oil.

Manufacturing:
For this application, polycarbonate is injection molded from polymer pellets. Drying of these pellets is critical to produce high clarity lenses. Due to severe cosmetic quality standards for optical lenses, 20 ~ 30% of the product may be rejected and disposed at various steps in the production process. While injection molding processes often have yields above 90%, many prescription lenses must be machined to the proper specifications from thicker polycarbonate "blanks". This process results in more than 80% of the polycarbonate material by weight to be removed and disposed or recycled.

Use:
The use phase for polycarbonate lenses is minimal, but includes any materials, chemicals solutions, soaps, or water required for periodic cleaning.

Disposal:
Despite the ability to recycle or downcycle this thermoplastic, most polycarbonate lenses are thrown away and end up in the landfill. This is due both to the lack of infrastructure for the recycling of this particular polymer as well as the fact that polycarbonate lenses are generally coated with other polymers or dielectric coatings to provide enhanced scratch resistance. Reuse of lenses is possible, but u ncommon due to scratching of the lenses over time as well as the fact that many lenses are of a specific prescription and size.

Environmental Issues:
Polycarbonate in its cured thermoplastic lens form is relatively inert with minimal environmental hazards. Questions have been raised about chemicals leaching from this plastic in other applications where liquids and/or high temperatures are involved. However, the chemical precursors for polycarbonate have environmental concerns including the high toxicity of phosgene and the potential role that bis-phenol A plays as an endocrine disrupter.

References:
[1]CES Selector version 4.6, Granta Design Limited, 2005.

Appendix L: Homework Assignment #10

Assignment:

Write a one page summary about working with your interdisciplinary team on the LCA project. Address the following questions as well as anything else that seems relevant. Be as specific as possible in your comments and try to avoid broad generalizations (**20 points**):

1) How was this team project different that other team projects with which you have been involved that were not interdisciplinary? (**5 points**)

2) Describe some of the positive outcomes of working specifically with team members from other disciplines? (**5 points**)

3) What were some of the challenges specifically related to working with members from other disciplines? (**5 points**)

4) How would you structure the project in order for students to be more engaged and to learn more? Provide specific suggestions to add to or remove from the project to improve it from your perspective. (**5 points**)

Appendix M: Quiz #1

Print Name: ___________________________ Signature: _________________________________

1. List the 4 main phases of the life cycle of a product (**4 points**)
   1. ____
   2. ____
   3. ____
   4. ____

2. List 2 reasons why material mass is such an important design criteria from an environmental impact perspective (**2 points**)

   1)

   2)

3. List any three of the environmental impact categories discussed in lectures or the readings and a potential endpoint associated with each one (**6 points**)

Impact Category	Possible Endpoint

4. Define the term **midpoint**, as related to environmental impacts, and provide at least one reason why midpoints are typically used for Life Cycle Impact Assessment compared to endpoints. (**2 points**)

5. Indicate whether the following statements regarding materials production energy, as defined in lectures and the CES reading, are True or False (**2 points**):

   a) *The energy to process materials by melting or deformation is generally higher than the production energy?*

   TRUE FALSE

   c) *The energy required to recycle a material is generally significantly smaller than the production energy so adding a recycled material stream to a process typically reduces the overall production energy?*

   TRUE FALSE

6. List any 2 specific potential enviromental impacts other than energy use and associated air emissions – one related to the extraction of minerals from the environment and one with the harvesting of biomass from the environment. (**2 points**)

   1)

   2)

7. List one example of a specific mineral, material, chemical, crop, etc. mentioned in any of the reading assignments and an associated environmental impact that should be considered in its life cycle (**2 points**)

Appendix N: Quiz #2

Print Name: ______________________________ **Signature:** ___________________________

1. List the four major steps for completing a Life Cycle Analysis (**4 points**)

    a) ____

    b) ____

    c) ____

    d) ____

2. List any 2 items which should be documented in the Goal/Scope for an LCA Project and explain why this specific information is important (**4 points**)

    a)

    b)

3. What is a "functional unit" and explain briefly why this is it necessary for comparative LCA (**2 points**)

4. Give an example of background inventory data that could be found in typical LCA databases. Explain one potential inaccuracy that could arise in using information from background databases (**2 points**)

    a. Inventory Data: ____

    b. POTENTIAL PROBLEM:

5. List one advantage and one disadvantage for using endpoints (DALYs, for example) rather than midpoints as characterization factors. (**2 points**)

    a) Advantage:

    b) Disadvantage:

6. Assume the functional unit for comparison of a hypothetical gasoline and biodiesel-fueled automobile is "*per 10,000 miles driven*". Determine the total Global Warming Potential (GWP) and Acidification

impact indicators using the characterization factors provided in the data tables below. Note the data are estimates chosen to ease calculations. Show calculations in margin for partial credit potential (**6 points**)

a) Fill out the missing table information

			Emissions (kg/gallon)	
Fuel	**Miles/gallon**	**gallons**	**CO_2**	**NO_x**
Gasoline	40		10	0.1
Biodiesel	50		1	0.2

	Emissions (kg)	
Fuel	**CO_2**	**NO_x**
Gasoline		
Biodiesel		

	Characterization Factors	
Chemical	**GWP (kg CO_2/kg)**	**Acidification (kg SO_x/kg)**
CO_2	1	0
NO_x	0	40

	Environmental Impact Indicators	
Fuel	**GWP (kg CO_2)**	**Acidification (kg SO_x)**
Gasoline		
Biodiesel		

b) Based on this simplified analysis, comment on which transportation mode is greener? Why?

Appendix O: Quiz #2, Make-Up

Print Name: ________________________________ **Signature:** ______________________________

1. Match the items on the right to the LCA process step with which it is best associated (**4 points**)

Goal/Scope	_______	A) Weighting factors
Inventory Analysis	_______	B) Functional unit
Impact Analysis	_______	C) Mass balance
Interpretation	_______	D) Characterization factors

2. Explain why the following functional units might not provide good comparisons (**2 points**)?
   a) Comparison of bus vs. automobile transporation using fuel economy (miles/gallon) as a functional unit

   b) Comparison of 12 ounce aluminum cans vs. 2 liter plastic bottles for soda using the container weight as a functional unit

3. Explain why "lifetime" or "extent of time" is an important consideration when defining the "functional unit" in a project scope. Provide a specific example to demonstrate your point. (**2 points**)

4. Give a specific example of both foreground and background inventory data that could be used for LCA. Explain one potential disadvantage in using this information from (**4 points**)

   a. Background Data: ____

   b. Potential Disadvantage:

   c. Foreground Data: ____

   d. Potential Disadvantage:

5. Explain the concept of Disability Adjusted Life Year (DALY) as well as an advantage and disadvantage of this measure as characterization factors. (**2 points**)

   a) Advantage:

   b) Disadvantage:

6. Assume the functional unit for comparison of a hypothetical incandescent light bulb to a compact fluorescent light bulb is "*per 10,000 hrs of use of the bulbs with same light output*". Assume the electricity source is the same for both. Determine the total Global Warming Potential (GWP) and Ecotoxicity impact indicators using the characterization factors provided in the data tables below. Note the data are estimates chosen to ease calculations. Show calculations in margin for partial credit potential (**6 points**)

a) Fill out the missing table information

Bulb	**Energy Use Watts (W)**	**Lifetime (hrs)**	**CO2 Output (kg/kW hr)**	**Mercury (mg/bulb)**	**Mercury (mg/kW hr)**
60 Watt Incandescent	60	1,000	1.0	0	0.01
60 Watt Fluorescent	20	10,000	1.0	1	0.01

	Emissions (per 10,000 hours)	
Bulb	**CO_2 (kg)**	**Mercury (mg)**
60 Watt Incandescent		
60 Watt Fluorescent		

	Characterization Factors	
Chemical	**GWP (kg CO_2/kg)**	**Ecotoxicity (kg Benzene/kg)**
CO_2	1	0
Mercury	0	100

	Environmental Impact Indicators	
Bulb	**GWP (kg CO_2)**	**Ecotoxicity (kg Benzene)**
60 Watt Incandescent		
60 Watt Fluorescent		

b) Based only on this simplified analysis, comment on which light bulb is greener? Why?

Appendix P: Quiz #3

Print Name: ________________________________ **Signature:** ____________________________

1. List any 5 different options for product end-of-life from least environmental impact (top) to most environmental impact (bottom) (**5 points**)
   1) ____
   2) ____
   3) ____
   4) ____
   5) ____
2. In terms of life cycle impact, explain why the top end-of-life option in your list is generally considered better than the bottom end-of-life option from an environmental perspective? (**2 points**)
3. In terms of life cycle, provide a specific exception to your list in which one of the lower ranked options could be considered to have less environmental impact than one of the higher ranked options. (**2 points**)
4. From an LCA perspective, explain why end-of-life options need to be considered in the design phase for products, processes, and systems (**2 points**)
5. Give an example of a current local, regional, or governmental policy that encourages better end-of-life choices and an example of a policy that discourages such choices. (**2 points**)
6. Give an example of the practice of *Industrial Ecology*, where industries try to mimic natural ecological systems in terms of closed loop end-of-life options (**1 points**)
7. List any 3 specific design or building choices for which credit is given in the LEED rating system for buildings (**3 points**)
   1)
   2)
   3)
8. Give two <u>environmental</u> benefits using LEED for building design (**2 points**)
   1)
   2)
9. Give an example of how LCA might provide credits differently than the current LEED rating system (**1 points**)

Appendix Q: Quiz #4

Print Name: ______________________________ **Signature:** ___________________________

1. Consider an LCA which compares wooden 2 x 4's to steel 2 x 4's for the framing of a residential house. 3 potential functional units are listed below. Indicate which one of the 3 is the best and explain why. For the other two, indicate why they are not particularly good functional units. (**6 points**)

   a) *The energy and resources needed to manufacture and dispose of the wood and steel for 1000 of each type of 2 x 4*

   b) *A specific 2000 square foot residential home built to the same building code using each material*

   c) *The cost and emissions for 10,000 lbs of wood and steel 2 x 4's*

2. Explain how weighting and normalization are different? Why is it useful in many situations to use weighting? Why is it useful in some cases to use normalization (**4 points**)

3. List two advantages and one disadvantages of using Streamlined LCA (**4 points**)

   1) Advantage **-**

   2) Advantage –

   3) Disadvantage

   4) Disadvantage

4. Look at the streamlined LCA matrix below and answer the following questions (**6 points**)

Appendix R: Project Assignment

Assignment:

In teams with 5 or 6 members, you will research and prepare a life cycle analysis for a product or process. Teams were assigned randomly by picking numbers and are detailed in the table below **-** a few adjustments were necessary to balance majors within each team.

The Life Cycle Analysis group report should include the following items:

1) **Product description** – what is the product, how extensive is product use, what are alternatives, etc.
2) **Goals and Scope** – what are the project goals, boundaries, assumptions, etc. and why were these chosen
3) **Responsibilities -** the report should clearly indicate who was responsible for each specific part of the project otherwise individual grading will not be possible
4) **Process flow diagram** – schematic showing general manufacturing processes
5) **Material selection discussion** – what materials are used in this product and what functional characteristics/properties drive this choice
6) **Input table** – what are the main inputs for the product within the project boundaries, where did this data come from, what is the data quality
7) **Output table** – what are the main outputs for the product within the project boundaries, where did this data come from, what is the data quality
8) **Impact Assessment** – what are the quantitative environmental impacts (SimaPro), what methods were used, network diagram, plots
9) **Quantitative comparison of at least two significant design or process changes** – SimaPro data comparing the baseline product to one or more product material, process, disposal, etc. changes
10) **Commentary and conclusion** – what does this analysis mean from an environmental perspective

Grading:

1) 40% overall group effort – everyone will get 40% of the overall written report score
2) 25% individual effort – the scope document must define your individual responsibilities
3) 20% multidisciplinary team component – all team members will be responsible for knowing basic parts of all 10 sections above as determined by meetings with the instructor in which each team member is asked general questions about any aspect of the project
4) 15% of grade will be an average of your teammates rating of your effort and contribution

Notes/Suggestions:

1) Keep your topic simple and one which has a lot of available data for manufacturing
    a. Need to be able to get a decent list of the primary inputs and outputs for your product/process
    b. Fewer process steps are better than many
    c. Complex products will be very difficult (car, cell phone, etc.)
    d. Offering an LCA to a manufacturing company might be an excellent way to get real product data
2) Be very clear in the report as to who was responsible for specific items (table in appendix would be nice)
    a. Choose one person be the "keeper" of the official software model
    b. Choose a subset of your team to compile the report
3) It is the responsibility of the team to determine responsibilities for its members
4) It may save research time to pick a product which uses one of your team members' materials.
5) The final report should not be longer than 15 pages including any references, figures, etc. There is no minimum, but reports without depth of content in the areas listed above will get lower grades.

6) The focus (and bulk) of the report should be the inputs, outputs, and impact assessment. Data, analysis, and network diagrams can be copied from SimaPro, however, I do <u>not</u> want a full input/output table from SimaPro. I suggest a reduced input table with key materials (kg), energy/fuel, and water (gallons) as relevant. The output table should be more detailed and SimaPro will allow you to sort outputs by quantity or impact. Choose some threshold and provide a list of the key outputs.
7) Use any report format you would like but suggestions are either standard report format (introduction, data, analysis, conclusions) or LCA format (Goal/scope, Inventory, Impact Assessment, Interpretation).
8) The instructor may be able to assist with significant team dynamic issues, but for the most part the team needs to solve its own problems

Suggestions for products of reasonable scope for this project:

- Bicycle, T-shirt, Food product, Plastic part, Wooden product (table)

Team Information

Number	Team	Name	Major
1	1	(names removed)	ME
2			MSE
3			ME
4			ISE
5			ME
6			ISE
7	2	(names removed)	ISE
8			ME
9			CEE
10			ISE
11			ME
12	3	(names removed)	ME
13			ISE
14			ISE
15			CEE
16			ME
17	4	(names removed)	ME
18			ISE
19			ME
20			IndD
~~21~~			~~ISE~~
22	5	(names removed)	ISE
23			ISE
24			ME
25			ME
26			ISE
27	6	(names removed)	ME
28			ME
29			ISE
30			ISE
31			ISE

Appendix S: Project Team Meeting Assignment

Assignment:

The instructor will meet with each group for ~10 minutes. Based on the team listing on page 2, groups 1 – 3 will meet on Tuesday and groups 4 – 6 will meet on Thursday in numerical order. Since the first 3 groups will have fewer days to prepare, this order will be switched later in the semester for additional group meetings.

The teams should prepare a one page memo with the following for discussion:

1) One or more ideas for the group product/process to be analyzed as well as several design or process changes for LCA comparison.
2) An initial idea of the general goal and scope including major boundaries and assumptions.
3) A list of tentative project responsibilities for team members.
4) A list of questions or concerns about the project or its details.

None of these areas has to be completely defined, but your team should have at least a topic and a good start prior to spring break. This memo will not be formally graded, but team members present will get points a few points for participation, preparation, and organization. If you cannot be present for some reason, your team members will be asked if you contributed to the team in order to receive these points.

Appendix T: Pilot Pre-Course Survey

1. Explain in a few sentences why you are taking this class?

2. List 3 reasons why engineers should be concerned about the environmental impact of their professional decisions.

   1)

   2)

   3)

3. Describe in a few sentences your current understanding of the general concept of Environmental Life Cycle Assessment Methodology (what is it, why do it, what does one do, what does it provide?)

4. Explain in a few sentences why engineers should perform LCA on products, processes, and systems

5. List the 4 main phases of the life cycle of a product

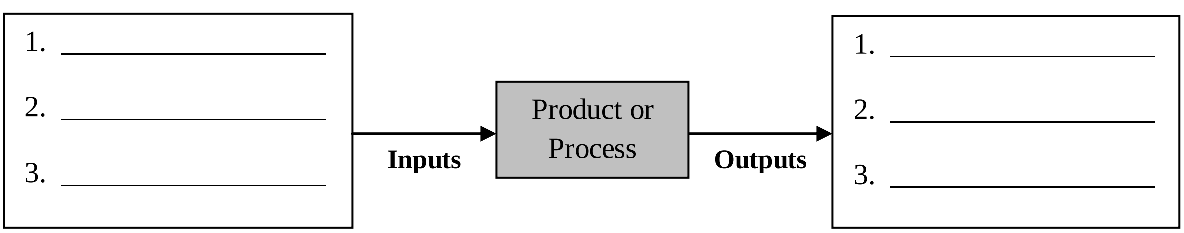
   1. ______________________________

   2. ______________________________

   3. ______________________________

   4. ______________________________

6. List 3 common inputs and 3 common outputs for products or processes that would be used in an LCA



7. List any 3 major environmental impact categories and describe one or more potential endpoints

8. List 3 specific sources for quantitative environmental data (more specific than "on the web")

   1)

   2)

   3)

9. List 3 limitations of current Life Cycle Analysis methods

    1)

    2)

    3)

10. Discuss in a few sentences why product design is a critical phase in the life cycle of a product

Appendix U: Pilot Post-Course Survey

1. Circle the degree to which you would recommend this class to other students in your discipline:

    Highly *Moderately* *Neutral* *Weakly* *Not at all*

    Explain why you would recommend the course at the level indicated.

2. What do you think are the most and/or least useful parts of this class? Indicate topics that you would add, remove, or change the level of emphasis.

3. Briefly comment on how the concept of product/process design presented in this class is different from other classes you have taken which discuss design.

4. Rate this class overall on scale of 1 – 10 compared to others in terms of learning and usefulness. Provide any comments if you'd like to clarify your answer.

5. Rate the amount of homework in this class on a scale of 1 – 10. Provide any comments if you'd like to clarify your answer.

6. Rate the difficulty of homework, quizzes, project on a scale of 1 – 10. Provide any comments if you'd like to clarify your answer.

7. Rate the amount and quality of the reading material on a scale of 1 – 10. Provide any comments if you'd like to clarify your answer.

8. Indicate whether you think the class should spend more, less, or the same amount of time on the CES software and SimaPro LCA software. Explain briefly.

9. Did you find the individual material/product presentations interesting and useful? Would you recommend these again or use the class time for other topics?

10. What do you think will be the biggest impact of this class on your future?

11. Please provide any other comments which you think could improve the class for next year.

12. List 3 reasons why engineers should be concerned about the environmental impact of their professional decisions.

    1)

2)

3)

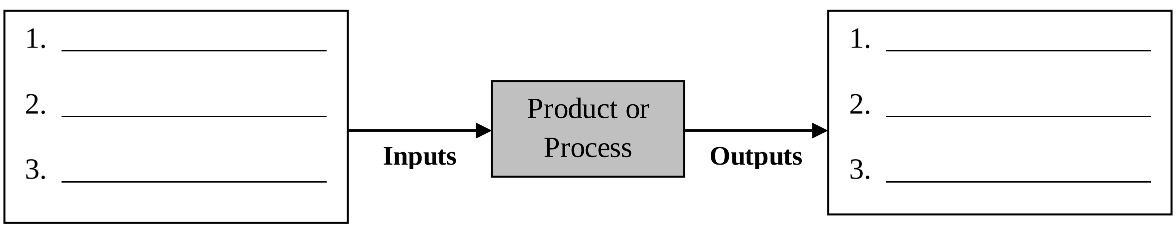
13. Describe in a few sentences the general concept of Environmental Life Cycle Assessment.

14. Explain in a few sentences why engineers should perform LCA on products, processes, and systems

15. List the 4 main phases of the life cycle of a product

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________

16. List 3 common inputs and 3 common outputs for products or processes that would be used in an LCA



17. List any 3 major environmental impact categories and describe one or more potential associated endpoints

1)

2)

3)

18. List 3 specific sources for quantitative environmental data (more specific than "on the web")

1)

2)

3)

19. List 3 limitations of current Life Cycle Analysis methods

1)

2)

3)

20. Discuss in a few sentences why product design is a critical phase in the life cycle of a product

Appendix V: Pre-Course Survey

1. Why you are taking this class? (check all that apply)

   [ ] required for the Green Engineering concentration
   [ ] fulfills an Engineering Science elective
   [ ] co-op/internship revealed industry interest in Green Engineering
   [ ] interest in the course from the course description
   [ ] concern about the environment and/or environmental issues
   [ ] possibly pursuing Green Engineering in/as a career
   [ ] foresee value beyond graduation
   [ ] résumé builder
   [ ] diversifying education
   [ ] gaining a different perspective of engineering
   [ ] other:

2. Which one of the following best describes your thoughts regarding concern for the environment in the design and manufacturing of products, processes, and systems (check only one)?

   [ ] Performance and cost should be the key design criteria followed by environmental issues to the extent that they do not significantly affect the former and no environmental rules or regulations are violated.

   [ ] The environment should be considered equally along with cost and performance in the design of a product

   [ ] Given potentially serious local and global risks, environmental issues should be the primary factor in product design and weighted more heavily than cost and performance

   [ ] Other:

The remainder of the questions relate to your current understanding of Environmental Life Cycle Assessment concepts and methodology. Answer honestly – your answers are important to assess what is learned throughout this course.

3. List 3 specific examples of how engineering practice can have adverse environmental impacts

   1)

   2)

   3)

4. Describe 3 benefits of Life Cycle Analysis for engineering products, processes, or systems

   1)

   2)

   3)

5. Describe 3 limitations for using Life Cycle Analysis for engineering products, processes, or systems

1)

2)

3)

6. List the 4 steps to completing a Life Cycle Analysis

   1) ______________________________

   2) ______________________________

   3) ______________________________

   4) ______________________________

7. List 2 advantages and 2 disadvantages of using stream-lined LCA compared to full LCA

   Advantage:

   Advantage:

   Disadvantage:

   Disadvantage:

8. List the 4 main phases of the life cycle of a product, process, or system

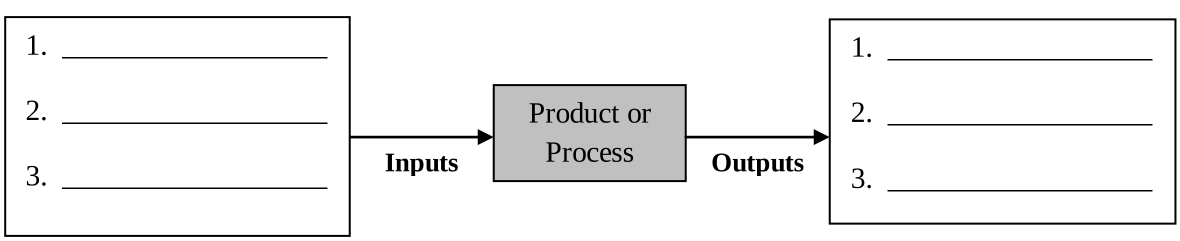
   1) ______________________________

   2) ______________________________

   3) ______________________________

   4) ______________________________

9. List 3 general inputs and 3 general outputs for products or processes that would be included in an LCA



10. List any 3 major environmental impact categories along with a potential midpoint and endpoint associated with each category

Impact Category	Potential Midpoint	Potential Endpoint

11. List 3 specific sources, one from each general category, where you can find quantitative environmental data

    1) Websites:

    2) Government Agencies:

    3) Software/Databases:

12. List 3 risks for not considering the environment in the design stage for a product, process, or system

    1)

    2)

    3)

Appendix W: Minute Survey #1

1. The pace of this class so far is (circle one):

Much too slow	*A little too slow*	*About right*	*A little too fast*	*Much too fast*

2. The relevance of the class information covered so far compared to what you think are important engineering skills with respect to the environment (circle one):

Not relevant	*Not sure if relevant*	*Somewhat relevant*	*Very relevant*

3. The lectures and format of this class are (circle one):

Boring	*Tolerable*	*Interesting*	*Engaging*

4. The clarity of the course outline and learning objectives for the class are (circle one):

Unclear	*Not sure*	*Somewhat clear*	*Very Clear*

5. What is the most interesting, useful, or valuable thing that you've learned so far in this class?

6. What question, topic, or issue covered so far is the least clear?

7. List one aspect of the course that you think is particularly good:

8. List one change to the class that would improve it from your perspective:

Appendix X: Minutes Survey #2

1. Comment on the effectiveness of the homework to reinforce and/or apply your knowledge of concepts covered in class (circle one):

Homework doesn't help reinforce class concepts	*Homework marginally reinforces class concepts*	*Homework does reasonable job of reinforcing class concepts*	*Homework helps significantly to reinforce class concepts*

2. Since the last survey, the degree to which the lectures engage the class has been (circle one):

Less Engaging	*About the same*	*More engaging*	*Very interesting and engaging*

3. Based on the written project assignment and class discussions, the expectations for the group project are (circle one):

Unclear	*Slightly confusing*	*Clear*	*Very clear*

4. What is the most interesting, useful, or valuable thing that you've learned so far in class **this week**?

5. What question, topic, or issue covered **this week** is the least clear?

6. List one aspect of the course that you think still needs improvement, explain briefly why, and offer a suggestion for improvement:

Appendix Y: Post-Course Survey

1. Circle the degree to which you would recommend this class to other students in <u>your</u> discipline:

Highly *Moderately* *Neutral* *Weakly* *Not at all*

Explain why you would recommend the course at the level indicated.

2. Indicate your thoughts concerning the level of coverage in the class on the topics below by placing a check in the appropriate boxes. Do not consider the relative importance of the topics, rather whether the amount of time and depth in each area was appropriate to helping you learn and apply critical concepts in these areas.

Topic	**Need a lot more focus**	**Need little more focus**	**About right**	**Need a little less focus**	**Need a lot less focus**
Extraction					
Manufacturing					
Use					
Disposal					
Materials Selection					
Environmental Impacts					
LCA methodology					
SimaPro LCA Software					
Sources for LCA data					
Streamlined LCA methods					
Use of LCA in design					

3. Briefly comment on how the concept of product/process design presented in this class is different from other classes you have taken which discuss design.

4. Rate this class <u>overall</u> compared to others in terms of learning and usefulness. Provide any comments if you'd like to clarify your answer.

High – good Mid – good Low – good Low – bad Mid – bad High – bad

5. Rate the <u>amount</u> of homework in this class. Provide any comments if you'd like to clarify your answer.

Much more than necessary A lot more than necessary Little more than necessary Little less than necessary A lot less than necessary Much less than necessary

6. Rate the <u>difficulty</u> of homework. Provide any comments if you'd like to clarify your answer.

Extremely difficult	Moderately difficuly	Slightly difficult	Slightly easy	Moderately easy	Extremely easy

7. Rate the difficulty of quizzes. Provide any comments if you'd like to clarify your answer.

Extremely difficult	Moderately difficuly	Slightly difficult	Slightly easy	Moderately easy	Extremely easy

8. Rate the difficulty of the project. Provide any comments if you'd like to clarify your answer.

Extremely difficult	Moderately difficuly	Slightly difficult	Slightly easy	Moderately easy	Extremely easy

9. Rate the amount of the reading material. Provide any comments if you'd like to clarify your answer.

Much more than necessary	A lot more than necessary	Little more than necessary	Little less than necessary	A lot less than necessary	Much less than necessary

10. How useful was the supplemental reading material in helping you learn the class concepts by providing another perspective. Provide any comments if you'd like to clarify your answer.

High – good	Mid – good	Low – good	Low – bad	Mid – bad	High – bad

11. How was this team project different that other team projects with which you have been involved that were not interdisciplinary?

12. Describe any positive effects of working specifically with team members from other disciplines?

13. What were some of the challenges specifically related to working with members from other disciplines?
14. How would you structure the project in order for students to be more engaged and to learn more? Provide specific suggestions to add to or remove from the project to improve it from your perspective.

15. Please provide any other comments which you think could improve the class for next year.

16. Which one of the following best describes your feeling about the concern for the environment in the design and manufacturing of products, processes, and systems?

[ ] Performance and cost should be the key design criteria followed by environmental issues to the extent that they do not significantly affect the former and no environmental rules or regulations are violated.

[ ] The environment should be considered equally along with cost and performance in the design of a product

[ ] Given potentially serious environmental risks, these issues should be the primary factor in product design and weighted more heavily than cost and performance

[ ] Other:

17. List 3 specific examples of how engineering practice can have adverse environmental impacts

    1)

    2)

    3)

18. Describe 3 benefits of Life Cycle Analysis for engineering products, processes, or systems

    1)

    2)

    3)

19. Describe 3 limitations for using Life Cycle Analysis for engineering products, processes, or systems

    1)

    2)

    3)

20. List the 4 steps to completing a Life Cycle Analysis

    1) ________________________________

    2) ________________________________

    3) ________________________________

    4) ________________________________

21. List 2 advantages and 2 disadvantages of using stream-lined LCA compared to full LCA

Advantage:

Advantage:

Disadvantage:

Disadvantage:

22. List the 4 main phases of the life cycle of a product, process, or system

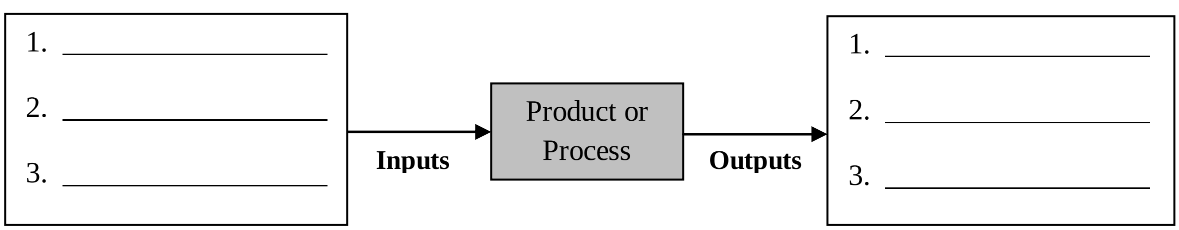
1) ________________________________

2) ________________________________

3) ________________________________

4) ________________________________

23. List 3 common inputs and 3 common outputs for products or processes that would be included in an LCA



24. List any 3 major environmental impact categories along with a potential midpoint and endpoint associated with each category

Impact Category	**Potential Midpoint**	**Potential Endpoint**

25. List 3 specific sources, one from each general category, where you can find quantitative environmental data

1) Websites:

2) Government Agencies:

3) Software/Databases:

26. List 3 risks for not considering the environment in the design stage for a product, process, or system

1)

2)

3)