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Sustainable Design: Integrate the Creative Thinking and Innovation into Graphical Communications

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Abstract

Engineering programs need to prepare the next generation of engineering professionals for tackling sustainability challenges that impact the social, environmental, and economic progress of the nation. This paper describes how the sustainable design concept was integrated into a freshman-level engineering gateway course that emphasized creative thinking and innovation through an open-ended team project. The goal of the study is to improve students' study skills to prepare them to be the next generation of engineering professionals. The expected outcomes are increased and improved innovative thinking, communication, and teamwork skills. A questionnaire-based methodology is used to assess the success of the study using data collected over three years. The assessment results indicated that students liked the sustainable design project and that their innovative thinking, communication, and teamwork skills were improved by it. A summary of lessons learned during the study is included and a future plan is discussed.

Introduction

Policy-makers worldwide have identified that today's engineering education should prepare the next generation of engineering professionals to undertake applied sustainability challenges that impact the social, environmental, and economic progress of the nation (ASEE, 1999; United Nations, 2002a, United Nations, 2002b); National Academy of Engineering, 2004, Byers, Seelig, Sheppard, & Weilerstein, 2013). Students should be able to apply the knowledge they learned in the class to solving real-world problems and applying nontraditional, creative thinking to sustainable engineering design concerns (Beiler, 2014). The importance of sustainability in engineering education is also recognized in the engineering accreditation criteria developed by the Accreditation Board of Engineering and Technology (ABET). ABET accreditation guidelines for 2014-2015 (ABET, 2013) include sustainability in at least two of the a-k student outcomes required for all engineering programs:

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and **sustainability**.

(h) the broad education necessary to understand the impact of engineering solutions in a global, **economic, environmental, and societal** context.

Criterion (c) clearly mentions sustainability, while criterion (h) refers to economic, environmental, and societal context, which are three components of sustainability.

Sustainability is a powerful, yet abstract, concept. The World Commission on Environment and Development's (WCED) (1987) originally defined sustainable development

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as “providing for human needs without compromising the ability of future generations to meet their needs.” However, this definition is hard to measure. The triple bottom line definition is often used in business and is more useful in assessing the sustainability of the engineering design since it measures economic cost, environmental impact, and social acceptability (Barrera-Roldan & Saldivar-Valdes, 2002).

Graphical Communications, an engineering fundamentals course, is designed to familiarize students with the basic principles of drafting and engineering drawing. It improves three-dimensional visualization skills of the students and teaches them the fundamentals of a computer aided design program — CATIA. Much of the instruction has traditionally focused on knowledge and comprehension, low levels of Bloom’s taxonomy (Bloom, 1956). However, students’ ability to use this knowledge and comprehension to explore real engineering design is unknown. Their project management ability, creative thinking, leadership, effective communication, and teamwork skills, which are criteria of the ABET (2013) program and are essential for the professional practice of engineering, are typically not assessed.

Previous research has shown that the integration of the sustainable design idea into the design process can provide students with an opportunity to learn about many factors that go into engineering design and that emphasized the importance of collaboration between students of various engineering disciplines (Bielefeldt, Jones, Price, Grahame, & Gillen, 2016; Price & Aidoo, 2013). The students can learn design process that emphasized environmental, economic, and social responsibility (Paudel & Fraser, 2013; Pfluger & Schulte Graham, 2014; Weber et al., 2014). This paper describes how the sustainable design concept has been integrated into a freshman-level engineering gateway course to emphasize creative thinking and innovation through an open-ended team project (Doyle, Baetz, & Lopes, 2009; Hertzog & Swart, 2015). The goal of the study is to build students’ study skills to prepare them to be the next generation of engineering professionals. The expected outcomes are an increase in innovative thinking and an improvement in communication, leadership, and teamwork skills.

A questionnaire-based methodology was used to assess the success of the study. Phase reports and final reports were required to evaluate their project management ability, innovation ideas, problem solving, and written communication skills. Peer evaluation was used to determine their collaboration, leadership, and teamwork skills. Team evaluation was done to test their effectiveness of oral communication. The assessment results indicate that students’ engagement with the sustainable design project increased and their innovative thinking, communication, and leadership. It was found that teamwork skills improved in the sustainable design project over the three years data were collected and analyzed. A summary of lessons learned during the study is included, and a future plan is discussed.

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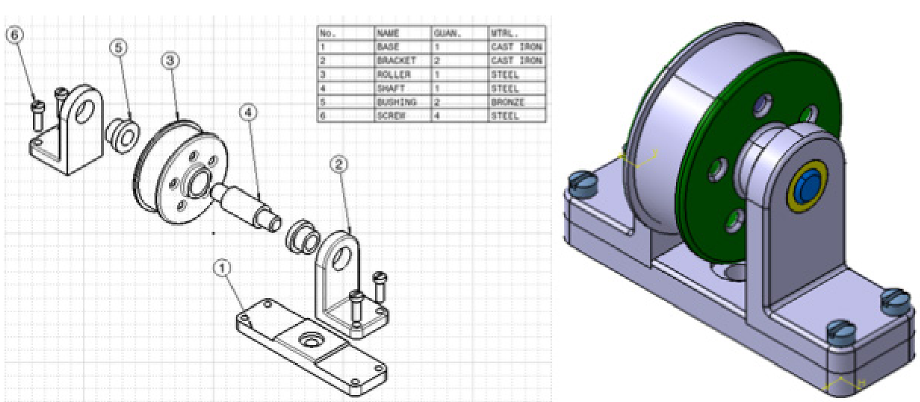
Course Curriculum and Structure

The goal of the Graphical Communications course is to familiarize students with the basic principles of drafting and engineering drawing, to improve three-dimensional visualization skills, and to teach the fundamentals of computer aided design using CATIA. After course completion, students will know the character and application of the various lines used in engineering drawings; be able to relate a scaled drawing to actual size and be able to produce drawings to scale; develop the ability to make acceptable freehand sketches with special understanding of the importance of proportions; know the principles of orthographic projection and apply these principles to construct multi-view drawings; understand the principles of isometric projection and apply these principles to isometric drawings; understand and draw auxiliary views; understand and draw interior views of an object as a section view; develop the techniques and rules of dimensioning and tolerances, and be able to apply these skills to a drawing; be able to read and understand a basic blue print; be able to understand and use CATIA as a computer aided drafting tool to produce multi-view, isometric, auxiliary and section views.

As a three-credit-hour semester course, students meet the instructor twice a week with each class lasting two hours. The first hour of each class is the scheduled lecture time; after the lecture, students are encouraged to use the rest of class time to ask questions and complete their assigned homework. During the 14-week semester, students learn the principle of orthographic projections and apply the principles to multi-view drawings by hand in the first four weeks. CATIA, a 3-D computer aided parametric design tool, is introduced after the hand drawing, followed by auxiliary views, section views, dimensioning, and tolerances. A final individual assembly project is given to the students to test their problem-solving skills under the direction of the instructor. Students need to complete at least ten-part assembly and constructing the final item following the constraint requirements. Figure 1 and Figure 2 show the exploded and isometric views of two previous individual final projects.



A B

Figure 1. A: Exploded view of a roller guide, B: 3-D view of a roller guide.

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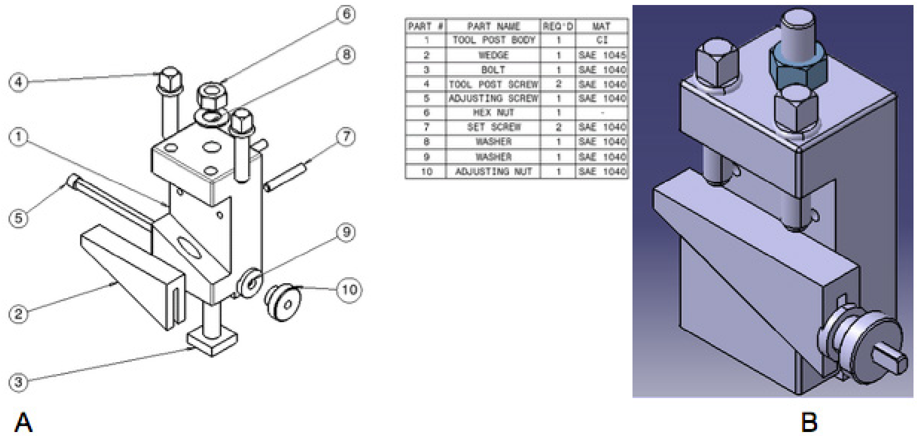

PART #	PART NAME	REQ'D	MAT
1	TOOL POST BODY	1	CI
2	WEDGE	1	SAE 1045
3	BOLT	1	SAE 1040
4	TOOL POST SCREW	2	SAE 1040
5	ADJUSTING SCREW	1	SAE 1040
6	HEX NUT	1	-
7	SET SCREW	2	SAE 1040
8	WASHER	1	SAE 1040
9	WASHER	1	SAE 1040
10	ADJUSTING NUT	1	SAE 1040

Figure 2. A: Exploded view of a roller guide, B: 3-D view of a roller guide.

At the end-of-course evaluation we found that students could follow the directions and accomplish the individual project on time. However, they felt a guided project lacked sufficient challenge, and that they would like to design a more complex model by themselves. According to the Bloom's taxonomy (1956), a guided individual project is considered as an application which can be used to test student problem solving ability as well as satisfying the ABET requirement. However, at this point in the students' education they typically have difficulty transferring material learned in the classroom to real life situations. They tended to become frustrated when they are confronting an open-ended design (Farris & Lane, 2005). To address this situation, investigate 21st century challenges, and the demand for creative and innovative thinking, an open ended sustainable design project was initiated starting spring semester of 2011. Students are required to design a product existing in today's market, then consider how to improve it by incorporating the concept of sustainability into their design, which involves engineering design feasibility, environmental impact, social and political consideration, and economic and financial feasibility.

In teams of two to four students, with self-selected team partners, students are required to finish their design project within six to eight weeks. Each student is expected to first present their design idea and innovative/creative methods for solving the problem to the instructor for approval. Students are encouraged to seek their teammates and determine the design idea from an approved list. To address the importance of sustainable design, and the philosophy and the intent of sustainable design, some real-world examples are instilled in students by showing a series of screencasts produced by Autodesk (2012) during class time.

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Students are required to perform research to support their innovative design, which must emphasize environmental, social, political, economic, financial, and engineering skills. The product must involve sustainable design concepts such as design for disassembly, design for repair, design for recycling, design for upgrade, and design for remanufacturing. Each assembled product includes at least ten unique parts and each part must be designed individually. The role of the instructor is as a facilitator to ensure student projects are delivered on time; direct guidance is limited to a minimum. In addition to their self-scheduled project time outside of the class, specific class time is dedicated to their project study as well, in which they can collaborate with their teammates to discuss the problems, and work on the project. They are encouraged to think outside the box and systematically design their project. All dimensioned drawing sheets, 3-D part models, and PowerPoint slides must be submitted online before the start of the presentation on the last day of the class. On the last day of the class, students appear in professional dress to present their work as a team. Each presentation lasts 8-10 minutes, and is followed by 2 minutes of question and answer time.

Confidential peer evaluation forms are used to evaluate their own performance and that of their teammates based on contribution and quantity of the work, interaction and collaboration of the teamwork, problem solving skills and quality of the work, time management, and willingness to be a team player. Team evaluations are completed by students in the class on the presentation day. Team evaluation criteria include presentation organization, slides content, presentation skills, aesthetics of the presentation, and team member participation. They are strongly encouraged to leave comments, as well as recommendations, to support their evaluation. At the end of the presentation, the instructor summarizes the student projects. A questionnaire-based methodology is used to assess the success of the study.

In spring semester, 2011, the multiple view drawings were not required, and students only need to finish the part design and the assembly design. Starting fall semester, 2011, detailed drawings were required, and students were required to show the multiple views, isometric view, and the dimensions on the drawing sheet for each individual part. Since fall 2012, in addition to the above assigned tasks, students are required to submit two sets of the design files. One is the original design based on the current existing product in the market, and the other one is the redesigned model to show the sustainable design. Students also must submit a written report as a team to document their research findings, design process, timeline, cost analysis, and conclusion. Each student additionally submits an individual logbook to document his/her work schedule and the tasks finished following their team timeline.

Project Study Outcomes

From spring 2011 through spring 2014, there were 289 students enrolled in the course, over 77% of which are male, 58% freshmen, and 62% aerospace engineering majors. The basic demographic breakdown for the class population can be found in Table 1.

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Table 1
Student background characteristics from the spring 2011 to the spring 2014.

	Spring 11		***Fall 11***		***Spring 12***		***Fall 12***		***Spring 13***		***Fall 13***		***Spring 14***	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Gender														
Male	21	81	30	86	41	77	75	82	69	83	48	79	28	85
Female	5	19	5	14	12	23	17	19	14	17	13	21	5	15
Total	26	100	35	100	53	100	92	100	83	100	61	100	33	100
Academic level														
Freshman	15	58	24	69	39	74	61	66	49	59	45	74	19	58
Sophomore	11	42	5	14	10	19	17	19	25	30	11	18	10	30
Junior	0	0	4	11	2	4	7	8	2	2	3	5	3	9
Senior	0	0	2	6	2	4	7	8	7	8	2	3	1	3
Total	26	100	35	100	53	100	92	100	83	100	61	100	33	100
Major														
Aerospace	22	85	27	77	38	72	65	71	53	64	38	62	27	82
Civil	1	4	0	0	1	2	1	1	0	0	1	2	1	3
Mechanical	3	12	3	9	6	11	12	13	17	21	8	13	2	6
Still exploring	0	0	2	6	4	8	2	2	7	8	6	10	1	3
Other (non-engineering)	0	0	3	9	4	8	12	13	6	7	8	13	2	6
Total	**26**	**100**	**35**	**100**	**53**	**100**	**92**	**100**	**83**	**100**	**61**	**100**	**33**	**100**

Note: Percentages are rounded to the nearest whole number.

The success of the project was evaluated through ABET outcomes *(a), (c), (g), (h), (k)*. ABET outcomes *(a)* and *(h)* are common assessment completed by all sections of Graphical Communications course. ABET outcomes *c*, *g*, and *h* are additional criteria of this project study. The evaluation rubric is shown in Table 2. ABET outcome *(a)* evaluates student understanding of freehand sketching and its application in the final project. ABET outcome *(c)* applies to student's understanding of sustainability and the application in the final project, specifically evaluation of the final report and presentation. ABET outcome *(g)* assesses student's oral and written communication skills and their teamwork skills based on the rubrics provided to them. ABET outcome *(h)* evaluates how to reflect the sustainability concept in their CATIA design, specifically parts and product are evaluated. ABET outcome *(k)* focuses on overall CATIA model design and drawing documentation. Some selective project topics are listed in Table 3.

Figures 3-6 show the rendered pictures and exploded views of student team projects in each year.

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Table 2
Evaluation rubric of the final project.

ABET Outcomes	Key Indicators	Excellent 2	Satisfactory 1	Unsatisfactory 0
(a) Ability to apply knowledge of mathematics, science and engineering.	Use lines, scaling, orthographic, isometric, and special views to depict design information. Apply dimensions and notes on the detailed drawing to communicate design information.	The key indicators listed are nearly always completed correctly.	The key indicators listed are mostly completed correctly.	The key indicators listed are frequently/ mostly not completed correctly.
(c) Ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.	Identify the problem and conduct the research to seek the feasibility solution through exploring environmental, economic, social impacts.	Is familiar with the concept of the sustainability and respects the impact of engineering solutions on the environment, economics, and society.	Is aware of the concept of the sustainability and the impact of engineering solutions on the environment, economics, and society.	Is unaware of the concept of the sustainability and the impact of engineering solutions on the environment, economics, and society
(g) Ability to communicate effectively.	Demonstrate effective oral and written communication skills and teamwork ability.	Create a comprehensive team report, demonstrate effective teamwork ability, and clearly present the project as a team.	Report missing some contents, some teamwork issues, and presentation is not clear.	Report missing most of contents, have significant team issues, and no presentation.
(h) Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.	Analyze the problem and apply the sustainability concept to CATIA design.	Create a new model with a design for disassembly, repair, recycling, upgrade, or remanufacturing within realistic constraints.	Create a new model with a design for disassembly, repair, recycling, upgrade, or remanufacturing without realistic constraints.	Create a new model with no sustainability involved.
(k) Ability to use the modern engineering tools necessary for engineering practice.	CATIA was used in the creation or design and documentation of parts and assemblies.	CATIA was used and documented, and used correctly.	CATIA was used and documented, but with two minor evident modeling or documentation issues.	CATIA was not used and documented, but with more than two evident modeling or documentation issues.

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Table 3
Selected student projects list.

Eco-friendly skateboard	Floor lamp
Piano keyboard	Eco-friendly guitar
Adjustable scooter	Wheeled luggage
Self-powered gym bike	Microscope
Ergonomic pen	Hover board
Lighter and flexible unicycle	Monitor mount
Ergonomic mouse	Comfortable office chair
Light year jetpack	User-friendly fire extinguisher
Interchangeable watch	Space relay power system
Eco RC helicopter	Fold-out-desk office chair
User-friendly keyboard	Life-proof smart phone case
Lighter pencil sharpener	Eco-friendly bicycle
Computer desk lamp redesign	Durable mechanical pencil
DJ controller	Computer desk lamp redesign
Solar powered wheelchair	Computer station

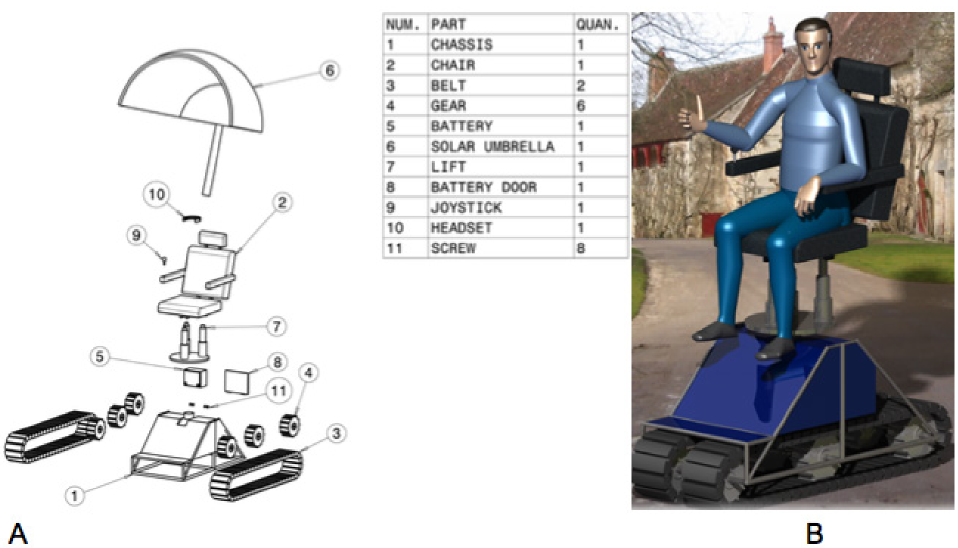

Figure 3. A: Rendered solar powered wheelchair, B: Rendered wheel chair from 2011.

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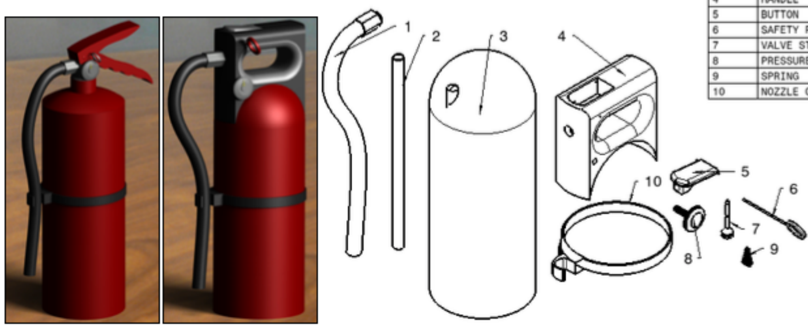
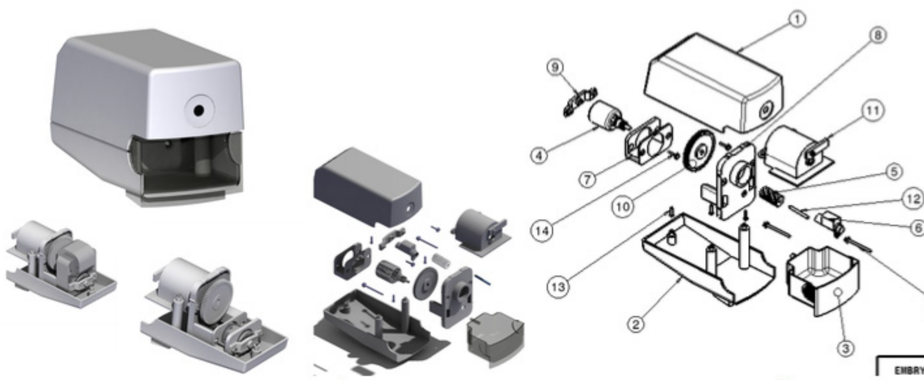


NUMBER	NAME	MATERIAL	QUANTITY
1	NOZZLE	RUBBER	1
2	SIPHON TUBE	FIBERGLASS	1
3	TANK	FIBERGLASS	1
4	HANDLE	ALUMINUM	1
5	BUTTON	RUBBER	1
6	SAFETY PIN	ALUMINUM	1
7	VALVE STEM	BRASS	1
8	PRESSURE GAUGE	GLASS	1
9	SPRING	STEEL	1
10	NOZZLE CLASP	PLASTIC	1

A B C

Figure 4. A: Original rendered fire extinguisher, B: Redesigned fire extinguisher with new handle design, C: Exploded view of the redesigned fire extinguisher from 2012.



#	NAME	MATIRIAL	QUANT.
1	TOP SHELL	PLASTIC	1
2	BOTTOM SHELL	PLASTIC	1
3	SHAVINGS HOLDER	PLASTIC	1
4	MOTOR	STEEL	1
5	BLADE	STEEL	1
6	SHARPENER BIT	STEEL	1
7	MOTOR MOUNT	PLASTIC	1
8	SEPERATOR	PLASTIC	1
9	MOTOR BACK MOUNT	PLASTIC	1
10	GEAR	PLASTIC	1
11	PENCIL GUIDE	PLASTIC	1
12	BLADE HOLDER SCREW	STEEL	1
13	SHELL SCREW	STEEL	3
14	PENCIL GUIDE SCREW	STEEL	2
15	MOTOR SCREW	STEEL	2

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A B

Figure 5. A: Rendered pencil sharpener with lighter and cheaper motor design, B: Exploded view of the pencil sharpener from 2013.

NO	NAME	NUM. OF PARTS	MATERIAL
1	FRONT COVER	1	PLASTIC
2	OUTER SIDE PANNEL	2	ALLUMINUM
3	LANDING BASE	1	PLASTIC
4	BOTTEM PIECE	1	PLASTIC
5	CONTROL BOARD	1	COMPOSITE
6	ENGINE MOUNT	1	PLASTIC
7	FRONT TRANSFER GEAR	1	PLASTIC
8	BACK TRANSFER GEAR	1	PLASTIC
9	INNER SIDE PANNER W/ MOUNT	1	ALLUMINUM
10	INNER SIDE PANNEL, BASIC	1	ALLUMINUM
11	MAIN ENGINE	2	ALLUMINUM
12	OUTER SHAFT	1	ALLUMINUM
13	INNER SHAFT	1	ALLUMINUM
14	SIDE FIN	1	PLASTIC
15	TAIL PIPE	1	ALLUMINUM
16	BLADE HOLDER	2	PLASTIC
17	TAIL ENGINE	1	ALLUMINUM
18	TAIL BLADE	1	PLASTIC
19	BOTTEM BLADES	2	PLASTIC
20	TOP BLADES	2	PLASTIC
21	ASME_B18_6_7M_M2x5_STEEL_COUNTERSUNK_FLAT_SLOTTED_MC_SCREW	26	ALLUMINUM
22	ASME_B18_6_7M_M2x3_STEEL_SLOTTED_PAN_HEAD_MC_SCREW	4	ALLUMINUM

A B

Figure 6. A: Rendered RC-helicopter with USB port and charging indicator, B: Exploded view of RC-helicopter from 2014.

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Assessment Results

An anonymous student satisfaction survey was implemented at the end of each semester to collect students' feedback regarding the team project from spring 2011 through spring 2014. On average, over 50% of students completed the survey each semester. Final project engagement was analyzed as shown in Table 4.

Table 4
Students' final project satisfaction ratings.

Question	Semester	n	Strongly disagree (%)	Agree (%)	Strongly agree (%)
Overall I like the sustainable design project	Spring 2011	15	7	47	47
	Fall 2011	27	4	48	48
	Spring 2012	37	11	62	27
	Fall 2012	67	36	48	16
	Spring 2013	45	13	69	18
	Fall 2013	24	11	75	13
	Spring 2014	15	0	67	33
I like to work on team-based project	Fall 2012	67	19	59	23
	Spring 2013	45	13	47	40
	Fall 2013	24	8	54	38
	Spring 2014	16	0	31	69
My real-world problem solving, creative thinking and innovation, communication, and teamwork skills were improved	Fall 2012	68	19	38	43
	Spring 2013	45	7	20	73
	Fall 2013	24	4	42	54
	Spring 2014	16	6	13	81

Note: Percentages are rounded to the nearest whole number.

In Table 4, from the first question, we can see that over 83% of the students liked the sustainable design project; this rate increased to 100% in spring 2014. In the second question, over 81% of students preferred teamwork and this rate increased to 100% in spring 2014. In the third question, the majority confirmed that the final project helped them improve their real-world problem solving, creative thinking and innovation, communication, and teamwork skills, and this rate has been increased from 80% in fall 2012 to 94% in spring 2014.

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More constraints were added in fall 2012 in the report section by asking students to follow a template to complete the report. Students also needed to submit two different sets of designs. One is based on the product which is existing in today's market, and the other is their improved model which can involve either new technology, or a more user-friendly design that incorporates a sustainable design idea into their project. However, after adding more workload to the final project, the students' satisfaction of the final project dropped significantly in Table 4 in fall 2012. They enjoyed the design process better than it's documentation. In addition, a proportion of the students did not appreciate incorporating sustainable/green solutions into the project. In the following semesters, project starting date has been continuously moved toward the beginning of the semester to give students more time to define their topic, choose partners, and complete their project work. A revised report template and sample reports were also provided to the students to reduce their workload considering the limited project time and other course load during the semester.

Some students' responses to the satisfaction of the project are shown as follows:

- I enjoyed the fact that we got to choose our own topic for the final project. I enjoyed choosing something that was interesting to me but that was also challenging.
- It was cool to work with new people and build something new.
- I liked it, thought it was interesting.
- The final project was great!
- More time so that students can create more complex products.
- I think the final project was the best part of the class. I wish that we could make our own design and it doesn't require to be eco-friendly. Not all students like eco-friendly products.
- The report asks for way too much. The CATIA project itself should be all.
- Allow for the option of individual or groups because some people would always rely on their teammates to do all the work.
- I rather enjoyed the final project because I was forced to learn different aspects of CATIA that weren't covered in class. This experience will be less likely to be forgotten because of the need to learn it.

Students rated the final project highly as an opportunity to understand an engineering design process. They enjoyed designing their own product, working with different classmates, and challenging themselves. They believed that they learned more from the final project by exploring tools, which were not covered in class time, teaching themselves the communication skills, working as a team, enhancing their presentation skills. The

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main complaint was the limited time assigned to the project. Since there were only three weeks left for the project, they felt they could do much better if more time could be assigned. Based on student feedback, starting in spring 2012, the project time was extended to eight weeks long. Students were also required to submit periodic progress report, an individual logbook, and a final written report from each team to document their design ideas, process, timeline, cost analysis, and research findings.

There are many challenges to successfully integrate sustainable design into a freshmen-level course with design components. Some of the most significant challenges are listed below, which needs to be considered and an effective solution found to successfully incorporate the sustainable design concept.

- Communication problems in the team, which needs the instructor to pay attention and address as early as possible
- Picking an appropriate topic is challenging to the students
- Open-ended projects maybe overwhelming to some students who still like to follow the instructor's direction
- Time management is still a big issue to most of the students, especially freshmen
- Self-seeking solutions is frustrating to the students
- Students need to adjust to solve real-world complex problem rather than the simple homework problems
- Teamwork is still a challenge to most of the students, especially freshmen
- It is hard to balance the amount of constraints and the creativity level in the project requirements

A formal assessment was completed using ABET rubrics in Table 2 besides the students-satisfaction survey. Table 5 displays the results of the formal assessment from 2011 to 2014, specifically sustainability design. ABET assessment criterion (c) identifies the increased understanding of the sustainability design concept. Students are able to identify the problem and apply the sustainability concept to the final project design. This could be attributed partially to the author's instruction experience. As more sustainability related project examples are given in the class time as an introduction, students' understanding of sustainability has been increased over the years. Their reports documented the problem statement, research findings, and how to solve the social, environmental, and economic challenges in their final project design. However, since most of them are still freshmen or sophomores, their creativity and innovation was not well grounded into their data/findings to provide arguments for the feasibility of the idea. Beiler (2014) supported this finding in her study as well.

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ABET assessment criterion *(g)* indicates that students' communication and teamwork skills improved as the class developed. The peer evaluation and team evaluations are confidential, which offer them an opportunity to evaluate themselves, their teammates, and their classmates. From the peer evaluation, most of them were able to collaborate with their teammates to accomplish the project within the given time, and self-evaluation reflected their personal effort. Team evaluation is used to evaluate the other team's presentation performance based on the given rubric. From the comments they gave on the team evaluation, it showed that they valued the opportunity, and left candid and constructive comments to the other teams. Periodically there were team issues such as miscommunication, personality, workload imbalance, and capability deficiency. Previous research has shown that giving students the specific instruction and grounded rules in this critical skill is essential to the success of teamwork (Dawes, Fisher, & Mercer, 1992; Matusovich, Paretti, Motto, & Cross, 2012; Paretti et al., 2011; Shuman, Besterfield-Sacre, & McGourty, 2005). The increased proficiency of the communications skills over the years suggests that combining the use of rules and specific instruction is of mixed success.

ABET assessment criterion *(h)* evaluates student's application of sustainability in CATIA part and product design. Overall students are proficient in the application of the sustainability concept in CATIA design and this proficiency is increased over the years. Since this is a fundamental course, student's CATIA ability limited their achievement of the creative and innovative ideas to some extent, which is reflected in the higher proficiency (Excellent) in ABET *(c)* and lower proficiency (Excellent) in ABET *(h)*.

Table 5
Results of formal assessment applied to final project 2011-2014.

	Proficiency Level											
	Unsatisfactory				**Satisfactory**				**Excellent**			
ABET criteria	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)
c	0	0	0	0	41	43	32	53	59	57	68	47
g	0	0	0	3	48	37	32	27	52	63	68	70
h	0	0	0	0	69	53	47	53	31	47	53	47

Conclusions

This paper has presented a transition from a guided individual project to a sustainable team project in a graphical communication course. The sustainable team project offered students an opportunity to learn the engineering design process while emphasizing environmental, economic, and social responsibility. It gave students opportunities to inquire into, collaborate on, design, assemble, and present their work, beyond those provided to

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previous classes. A questionnaire-based methodology was used to assess the success of the study. The assessment results indicate that student's enjoyment of the sustainable design project increased and their innovative thinking, communication, and teamwork skills were improved in the sustainable design project over three years data analysis. They were able to think outside the box and solve real-world problems, which enables them to solve company, country, even global challenges (Reid & Ferguson, 2011).

It is believed that by integrating sustainable design concepts into the final project students learned the importance of innovation and teamwork. They also learned engineering design that emphasized environmental, economic, and social responsibility. An important next step is to determine how the sustainable design project that emphasizes innovation and teamwork influences specific learning outcomes such as students' ability to master the material (Barron & Hulleman, 2006), deeper understanding of course topics, and student motivation and self-efficacy. Self-efficacy has been shown to be strongly linked to their motivation to succeed in the class (Hutchison, Follman, Sumpter & Bodner, 2006; Zimmerman, 2000). It has been found that students with high efficacy are more likely to undertake difficult tasks, work harder, and persist longer at the tasks than the students with low efficacy. Surveys should be given to the students when they finish upper-level courses to check the impact of the sustainable design project on their competence and ultimately their performance in other classes.

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