Considering Engineering Design in a Broader Context in Lower Division ECE Courses

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***Abstract*—This is an innovative practice Full Paper. Two of the seven ABET student learning outcomes (SLOs) require students have the ability to make informed judgements (SLO 4) or produce solutions (SLO 2) with consideration of global, economic, societal and environmental factors. Many engineering programs often meet these ABET outcomes through providing specifically tailored courses (such as a first-year and/or senior design experience) that address engineering design in a broader context. While these approaches can be effective, there is a need to infuse engineering design in a broader context throughout the existing discipline specific curriculum. This paper provides two examples of activities (a life cycle analysis lab and an inclusive design reflection) that help students put engineering design in a broader context in two existing sophomore level ECE courses. It is our hope that this paper will give electrical and computer engineering faculty (and engineering faculty in general) concrete ideas on how to infuse engineering design into a broader context in their existing technical coursework.**

Keywords—ABET, Life Cycle Analysis

I. Introduction

ABET (Accreditation Board for Engineering and Technology) accreditation "provides assurance that a college or university program meets the quality standards of the profession for which that program prepares graduates." [1] Two of the seven ABET student learning outcomes (SLOs) require students to have the ability to make informed judgements (SLO 4) or produce solutions (SLO 2) *with consideration of global, economic, societal and environmental factors*. In other words, ABET requires that students learn the ability to consider engineering design in a broader, more sustainable, and more inclusive context.

Many engineering programs meet these ABET outcomes through providing specifically tailored courses that address engineering design in a broader context – such as first-year design experiences [2-3], service learning courses [4-7], and/or capstone design experiences [8-13]. While these design approaches can be effective, one or two isolated courses rarely allow for a full transformation of perspectives or understanding [14]. Thus, there is a need to infuse engineering design in a more sustainable, and more inclusive context more often and throughout existing discipline-specific curricula [14-15].

Some examples on how to infuse the ideas of putting engineering designs into a broader context within discipline specific courses include teaching sustainability in manufacturing/mechanical engineering [16], civil engineering [17], materials engineering [18], and electrical and computer engineering (ECE) [19] or teaching social justice / sociotechnical issues in ECE [20-25], materials engineering [26] and mechanical engineering [27]. This paper adds to this body of work by providing examples of two activities that put engineering design in a broader context in two ECE courses. More specifically we describe a Life Cycle Analysis (LCA) Lab for a sophomore level Electric Circuits II Laboratory and an Inclusive Design Reflection for a Digital [Design Studio course to get students to specifically look at economic, environmental, and/or societal implications of their designs.

This paper is organized as follows. Section II provides the write up of the Life Cycle Analysis (LCA) lab we designed for our sophomore level Electrical Circuits II Laboratory course and Section III provides the prompt for the Inclusive Design Reflection we use in our sophomore level Digital Design Studio course. Section IV provides the methodology we used to assess the effectiveness of these activities in terms of their capacity to increase student's ability to consider engineering design in a broader context and Section V presents the results. We conclude in section VI.

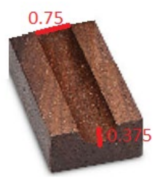
II. LCA Lab

Our sophomore level Electric Circuits II Laboratory meets for 3 hours once a week for 10 weeks. Each week, students build simple circuits that explore different uses of op-amps, capacitors, and/or inductors that they then combine into one Rube-Goldberg machine at the end of the course. This Rube-Goldberg machine involves moving a ferrous marble down a track while making use of the circuits they built. Although the design of the Rube-Goldberg machine is primarily for instructional purposes (i.e. learning how different circuit elements work and how to build practical circuits), we wanted to add an aspect of incorporating more global, economic, and environmental issues into engineering design by introducing the concept of life cycle analysis. Performing a life cycle analysis on a design can take months, if not years, by trained professionals, so this lab was designed to focus on the analysis of one very small part of the students' design – the track piece. Below we provide the lab in its entirety (although in a different text format) so that other instructors can easily adopt portions or all of the activity. Note that the lab makes use of a Granta EduPack (formerly CES EduPack), a software package often used by materials engineers, which provides a database of materials and process information, materials selection tools and a range of supporting resources [28]. Even though many university programs may not have access to this software, the goal of providing the lab in its entirety is to give faculty concrete examples of what questions to ask students or what facets of LCA to explore when adding a similar module to their own courses. Other LCA tools also exist that could be utilized for this lab, should Granta EduPack not be available. A simple example is Streamlined Life Cycle Analysis [29]

A. *Pre-Lab*

The questions below will give you some numbers that you will use for calculations and/or comparisons in this week's experiment.

1. Suppose you have a track piece that is 6 in long, 2 in wide, and 1 inch high and has a cylindrical cutout that is 0.75 inches in diameter. Calculate its volume in cubic inches.



2. On average, how much energy (in kWh) does each American use in their home per year? (see http://shrinkthatfootprint.com/average-household-electricity-consumption)

3. How much energy (in KWh) did your household use in the last month (look at your utility bill)? If you multiply this by 12 months and divide by the number of people in your household (to obtain kWh per person is househould / year), how to do you compare to the average from the question above?

4. How much energy is in one gallon of regular unleaded gasoline (in kWh)? (see https://en.wikipedia.org/wiki/Gasoline_gallon_equivalent)

5. How many pounds of CO2 are produced from burning one gallon of gasoline? (see https://www.eia.gov/environment/emissions/co2_vol_mass.php)

6. If the average person drives 12000 miles per year and gets 20 mpg with their car, how many pounds of CO2 do they produce from driving each year? How much energy do they consume (in KWh) from driving each year?

7. Knowing how much you drive per year and the gas mileage of your car – how many pounds of CO2 do you produce from driving each year? How much energy do you consume (in kWh) from driving each year? Note: If you do not drive, calculate for an immediate family member.

B. *Purpose*

1. To learn the stages of Life Cycle Analysis
2. To learn how to quantify effects of engineering design choices on economic and environmental systems.

This experiment relates to the following course learning objectives:

1. Understand the concept of life cycle analysis
2. Become familiar with how engineering designs affect natural, economic, and social systems.

C. *Background*

In this course, you'll be building upon skills you learned in EE143 (breadboarding, soldering, PCB design, 3-D printing, Arduino programming, circuit simulation, using test and measurement equipment, etc.) in addition to learning about uses of new components – primarily inductors and capacitors. To introduce these components in a creative and fun way, each weekly experiment will become a piece in a Rube Goldberg Machine (RGM) – a machine where one stage triggers the next stage which triggers the next stage, etc. Rube Goldberg was a cartoonist, author and engineer who became famous for drawing overly complex machines to accomplish simple tasks. If you are interested in learning more about Rube Goldberg, "Google" his name as there are numerous articles about his life.

Before we dive into building stages of our RGM, we'd like to introduce you to the concept of Life Cycle Analysis – an important concept to keep in mind when beginning any engineering design. Because it would take years of study and teams of people to complete a Life Cycle Analysis of our entire RGM, this lab will focus on looking at the LCA of one very small component of many RGMs – a track piece (many RGMs involve marbles/balls rolling down some kind of track). We'll use an LCA software package to analyze the cost and life cycle of a track piece made out of different materials and with different processes. We'll also introduce you to (or remind you of) the concept of E-waste and methods you can take to reduce your amount of E-waste in your designs.

D. *Life Cycle Analysis*

Life Cycle Analysis, also called Life Cycle Assessment, is a tool for examining the total environmental impact of a product through every step of its life – from obtaining raw materials all the way through making it in a factory, shipping it, selling it in a store, using it in the workplace or at home, and disposing of it. The five stages of LCA are depicted in Figure 1 below. Note that these stages sometimes have different names and sometimes are divided into 6 instead of 5 stages.

A product that is designed to live through one cycle (from extracting resources to end of life) comes from a concept known as 'cradle-to-grave' thinking. However, starting in the early 2000s, 'cradle-to-cradle' thinking was introduced. "Cradle-to-cradle" thinking would design the products and systems in a way which results in taking-back products at the end of its useful life and turning it into new products of equal, if not greater, value. Cradle-to-cradle thinking uses concepts like reusing, recycling, and remanufacturing, to increase the lifetime of a product and reduce environmental impact.

Fig 1. Life Cycle Assessment Steps (adapted from [30])

Major advantages of performing an LCA on a product include:

- The ability to claim one product is better than another
- The ability to narrow in on the area where the biggest reductions in environmental impacts can be made
- The ability to narrow in on the area where reducing costs can be made
- The ability to qualify a product with an eco-label

A major disadvantage of performing an LCA is that it might not always lead to a 'golden' solution for your design. For example, can an LCA tell us if it is better to make cloth diapers or paper diapers for babies? Performing the LCA on both products results in the following:

Life-Cycle Analysis of Disposable and Reusable Diapers (based on weekly diaper needs) (Table I)

TABLE I. LIFE-CYCLE ANALYSIS OF DISPOSABLE AND REUSABLE DIAPERS (BASED ON WEEKLY DIAPER NEEDS) [31]

Resource Category	Disposable Diaper	Reusable Diaper
Raw Materials Consumption (lbs)	25.30	3.60
Energy Consumption (Btu)	23,290.00	78,890.00
Water Consumption (gal)	23.60	144.00
Atmospheric Emissions (lbs)	0.09	0.86
Waste Water Effluents (lbs)	0.01	0.12
Process Solid Waste (lbs)	2.02	3.13
Post-Consumer Waste (lbs)	22.18	0.24
Total Costs ($/week)	10.31	7.47-16.92

From this data, we can make the following conclusions [31]:

- Disposable diapers create less atmospheric emissions, waste water effluents, and solid waste (feces processing) than reusable diapers.
- Reusable diapers use less raw material for production and create less post consumer waste than disposables.

However, it is difficult to say which one is "better."

Similar studies have been done on single use natural tree vs. multi-use artificial tree [32] or paper vs. plastic grocery bags [33].

Still, other LCAs do result in definite conclusions. For example, when comparing incandescent light bulbs with compact fluorescent (CFLs) and Light Emitting Diodes (LEDS), we see a huge environmental savings with modern LEDS on all fronts (Figure 2):

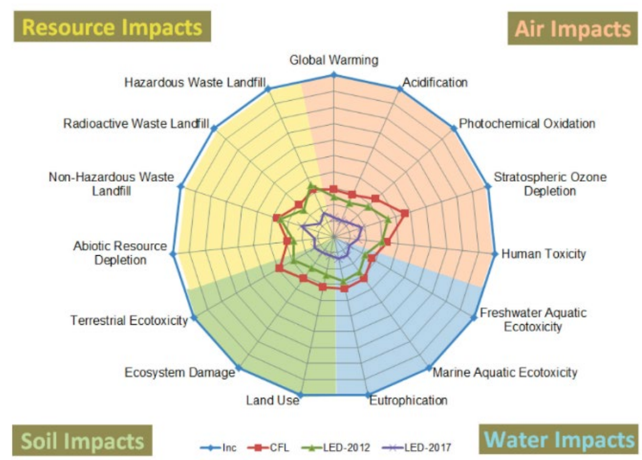


Fig 2. Severity of Environmental Impact Relative to Incandescent Lamp [34]

E. E-Waste

With LCA and 'cradle-to-cradle' thinking, we can design products that minimize environmental impact and waste. However, at some point, many of our electronic designs will reach an end-of-life and end up as e-waste. E-waste is a popular, informal name for electronic products (such as computers, TVs, stereos, copiers, cell phones, etc.) at the end of their 'useful life.'

In 2003, California passed the Electronic Waste Recycling Act which administratively regulates the systems used to recover and recycle certain portions of the electronic waste stream and makes it illegal to dispose of your E-waste with your regular garbage.

You can reduce your E-waste by:

- **Reducing** your generation of e-waste through smart procurement and good maintenance. Buy electronics that meet the energy-star rating and use all non-hazardous materials (see RoHS compliance). Use your electronics for as long as you can and learn to repair it
- **Reuse** still functioning electronic equipment by donating or selling it to someone who can still use it.
- **Recycle** products that cannot be repaired. A list of E-waste recycling locations in San Luis Obispo can be found here: http://iwma.com/what-to-do/ewaste/

F. RoHS Compliance

RoHS is a product level compliance based on the European Union's Directive 2002/95/EC, the Restriction of the Use of certain Hazardous Substances in Electrical and Electronic

Equipment (RoHS). Products compliant with this directive do not exceed the allowable amounts of the following restricted materials: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), with some limited exemptions." (definition from Thomas Net)

The United States has no federal law regulating hazardous substances, but the US must comply with RoHS if they wish to trade with the EU. In addition, individual states have laws regulating hazardous substances, including California's Electronic Waste Recycling Act (known as the California RoHS) mentioned above.

G. Procedure

1. Conduct a Cost Analysis

We would like to compare the cost differential between manufacturing a plastic 3-D printed track piece vs. purchasing a plastic track piece that was mass produced.

a. Open the CES software and click on Level 3 Eco Design.

b. Click on All Materials and then locate Polymers:plastics,elastomers -> Plastics -> Thermoplastics -> ABS -> Unfilled -> Injection molding, platable and double click

c. Have a look at all of the information the datasheet about this material provides. Based on the datasheet, answer the following questions using the high end of the estimates:

i. Knowing the volume of your track piece (Pre-lab question 1), calculate the mass (in pounds) of your track piece made of 50% dense ABS (you can find the density in the datasheet).

ii. What is the estimated price of ABS(in USD/lb)?

iii. Is this material RoHS compliant?

iv. How much energy is required for primary production of 1 pound of this material in KWh (convert from BTU)? How many pounds of this material would you have to make to match the average monthly energy consumption of a person in a household in the US? (Prelab question 2)

v. If you were to completely combust 1 pound of this material at the end of its life, how much CO2 would you release into the atmosphere? How many pounds of this material would you have to combust to match the average yearly CO2 emissions of a passenger car (Prelab Question 6)?

vi. What percentage of this material is recycled in the current supply?

d. Click on ProcessUniverse at the bottom of the datasheet. Select Shaping -> Additive Manufacturing -> Deposition Methods -> Fused deposition and double click. Notice that this is the process used for 3-D printing. Read about the process.

e. Click on Settings (at top of page) -> Numbers and select the check box "Display data ranges as average values" -> Apply -> OK

f. Scroll down to where you see the chart of relative cost index vs. Batch size. Click on the function symbol in the upper right corner of the graph.

g. Modify the parameters to be the following:

Capital Write off Time: 5

This is the amount of time it takes for the equipment to depreciate to no longer useful (typical values are 5 years for small scale processing, 10 years for heavy industry equipment, and 20 years for utility equipment)

Component Length: 0.5

This is the length of our track peice

Component Mass: Enter value from a 0.206

Discount Rate (%): 5

This is an economic parameter set by the Federal Reserve. Also known as interest rate. Low interest rates are around 2-3%, more typical is 5%

Load Factor: 0.5

This is the fraction of time the machine is in use (a value of 1 means the equipment is running 24/7 – a value of 0.5 means it operates in full production for 12 hours a day)

Material Cost: Enter value from b 1.04

Overhead Rate: 150

This represents the costs not associated with direct production (including labor, benefits, R&D, royalties, rent, utilities, janitorial services, etc.) Estimated values are $150/hr in US, $50/hr in China, $30/hr in Bangledesh

h. Click apply and copy the graph. What do you notice about the cost vs. batch size? Why is this the case?

i. Now suppose we produced this product in China instead of the US (change the overhead rate to 50 and click apply). Take a screen shot of the new graph. How does the overall price of the product compare?

j. Now let's compare this process with a different process used for mass produced plastics. You should see a tab named Links near the top of your screen (to the left of a tab named Fused deposition). Under Shaping choose Molding -> Injection -> Standard -> Thermoplastics. Read about the process.

k. Scroll down, click on the function symbol in the upper right corner of the graph and modify the parameters to match those found in g).

l. Click apply and take a screen shot of the graph. What do you notice about the cost vs. batch size? Why is this the case?

m. Now suppose we produced this product in China instead of the US (change the overhead rate to 50 and click apply). Take a screen shot of the new graph. How does the overall price of the product compare?

2. Conduct an Eco-Audit

To access the Life Cycle Analysis software follow the instructions provided by the instructor.

a. Under databases, choose Level 3 Eco Design.

b. Click on Eco Audit at the top of the screen. Name the product 'US Track'

c. Under Material, manufacture and end of life, enter Qty as 10 and Component name as Track. 'For the Material, select Polymers->Plastics->Thermoplastics->ABS->Unfilled->Injection molding, platable and click OK

d. Set the following remaining parameters:

Recycled Content:	0% (new material)
Mass:	0.206 (mass of one track piece)
Primary process:	Polymer molding
Secondary process:	None (leave blank)
%removed:	0
End of Life:	Recycle
%recovered:	4% (only a fraction can be recovered

e. Under transport, suppose you manufacture this part in Long Beach and you transport it up to Cal Poly via a 14 tonne 2-axle truck. Give this transport a name, select the appropriate transport type and enter the mileage.

f. Under use, indicate that this product will have a life of 1 year and will be used only in the United States.

g. Now under Report, click on summary chart to see how much energy and CO2 is consumed in each stage of the life cycle. What is the total CO2 produced across all life cycle stages for these 10 track pieces (including how much CO2 can be gained back from the system through recycling)? How does that compare to 1 gallon of gasoline? (Pre-lab question 5)

h. We'll be using this 'US Track' product to compare with other variants of this product. Now click on Compare with -> Copy of Current Product (located next to New, Open, Save). Change the product name to 'US Track from China.' Now, we must first ship it by ocean freight from Shanghai to Long Beach and then ship it to Cal Poly. Add this row to the transport section. How does this affect energy and CO2?

i. Click on the US Track (top of screen under Tools) again and then hit Compare with -> Copy of Current Product. Name this product 'US Recycled' and Change the % recovered to 90%. How does this affect energy and CO2?

j. Copy your graphs of Energy and CO2. What can you say about the relative energy and CO2 use of each life cycle stage? About the value of recycling? What do these graphs show in regard to energy savings versus cost? Assume production cost in the US is 2.5 times greater than production cost in China.

3. Discussion

Using the graphs you gathered from sections 1 and 2, compare them with the provided graphs <<omitted in this paper due to space constraints>> for making a track piece from Wood (Western Douglas Fir). Write a brief report (that includes your graphs) to make a case about whether we should make track pieces out of plastic or wood. At the end of your paper, include a paragraph about what you found most interesting / astonishing about this whole experiment. Do you now have a better understanding of what elements go into quantify the effects of engineering design choices on economic and environmental systems?

III. Inclusive Design Reflection

Our sophomore level Digital Design studio course (a course combining lecture and lab in one classroom setting) meets for 6 hours a week (either in 3 two hour sessions of 2 three hour sessions) for 10 weeks. Students learn how to design and build simple digital circuits (in a hardware description language) and then are asked to design a digital circuit of their choosing for their final (1.5-2 week) course project. As part of the project report write-up, students are asked to reflect on the inclusive nature of their designs. Specifically, students are asked to:

Write a paragraph or two that considers who is able/not able to use your design. (Consider age, race, physical ability, national origin (language), religion, and gender)

We introduce this reflection by providing examples of engineering designs that perhaps did not specifically consider this question: such as a soap dispenser that could not detect black skin, air bags designed for the average male (instead of female or child) size, and facial recognition algorithms that could not detect Asian faces. The intent of this reflection is to help students begin to think about some of the societal implications of their designs.

IV. Methodology

In order to access the effectiveness of the LCA and Inclusive Design Reflection activities in their ability to increase student awareness of placing engineering designs in a broader (more sustainable or more inclusive) context, we conducted these activities in multiple sections of their respective courses and asked students to complete an Institutional Review Board (IRB) approved anonymous survey about their experience with the activity. As our college's student demographics are predominately white male, non Pell-eligible students (e.g. higher income students) who started the university as first time first year students (rather than as transfer students), no demographic questions were asked to keep students anonymous in the survey. The instructor posted a link to the survey on the course's Learning Management System and gave students multiple reminders via email and announcements in class asking them to voluntarily complete the surveys. The survey questions are listed below.

A. LCA Experiment Survey

1. Did you know about the concept of Life Cycle Analysis prior to the class? If yes, choose other and list where you learned about it?
2. Prior to this class, did you know software like CES existed to help engineers determine the economic and environmental impacts of selected materials?
3. Please rate your level of agreement with each statement (Likert Scale 1- Strongly Disagree -> 5 Strongly Agree):
    a. I liked working on the LCA lab
    b. The LCA lab made me more aware about how design choices have global economic impacts
    c. The LCA lab made me more aware about how design choices have global environmental impacts
    d. The LCA lab was a waste of my time.
4. The Electrical and Computer Engineering Departments at Cal Poly are accredited by ABET. Did the Life Cycle Analysis Lab help you 1-Introduce, 2-Develop, or 3-Master the following:
    a. (SLO2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
    b. (SLO4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. What was your main take away from the LCA lab? (long answer)

B. Inclusive Design Reflection Survey

1. Did being asked to reflect on the inclusivity/accessibility of your design cause you to change your design process or modify your project in any way?
2. Before this class, were you aware of any real-world engineering projects that exclude users (like the soap dispenser project talked about in class)? If so, list those projects – if not, leave blank.
3. Have you ever been personally affected by an inclusivity/accessibility issue with a product/device/engineered system? If so, please explain, if not, leave blank.
4. Before this class, did you ever participate in an engineering design project that explicitly asked you to reflect on accessibility/inclusivity as a design metric? If so, please list those projects, if not, leave blank.
5. What were your general impressions about being asked to reflect on the inclusivity/accessibly implications of your design? (long answer)

V. Results

We conducted the LCA Experiment and Inclusive Design reflection in four sections of our Electric Circuits II laboratory (n=75) and in two sections of our Computer Design studio course (n=55) respectively, in the Winter 2022 term. Of the 75 students surveyed for the LCA experiment, 26 responded (35% response rate) and of the 55 students surveyed for the Inclusive Design Reflection, 9 responded (16% response rate). The larger response rate for the LCA survey was likely due to the survey being issued during week 2 of the course (as the LCA lab was given during week 1) whereas the inclusive reflection survey was issued after the course was completed (as the design project was due at the end of the course). In this section, we present the results of the surveys.

A. LCA Experiment Results

Figure 3 shows the result to LCA survey questions 1 and 2 which speak to the level of prior knowledge about LCA and the existence of tools to support LCA. Of the 19% that said they had prior knowledge of LCA, 2 students said they acquired that knowledge through common knowledge, 2 through high school courses and 1 through the university's honors program. The overwhelming majority of students responded they had never been exposed to the concept of LCA (nor tools associated with LCA). This result suggests that it is important for us to provide that exposure for our students if we wish for them to more deeply consider broader impacts of their engineering designs.

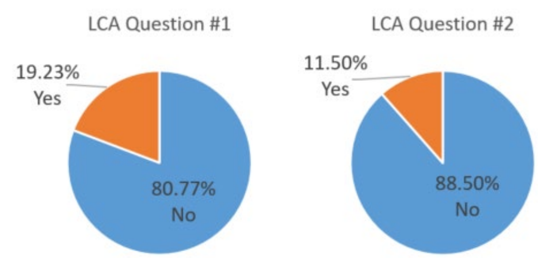


Fig 3. LCA Survey Results to Questions 1 and 2

Table II shows the results to LCA survey question 3 which speak to the students' self-evaluation of how well the LCA experiment made them more aware about how their design choices have global economic and environmental impacts. Not a single student disagreed with the statements about the lab providing increased awareness and an overwhelming majority actually enjoyed doing the lab and felt the lab was a good use of time.

TABLE II. LCA Survey Results to Question #3. The %Agree column is the percentage of students who responded with a 4 or 5 and the % Neutral column is the percentage of students who responded with a 3 on the Likert scale.

Statement	Average	%Agree	%Neutral
I liked working on the LCA lab	4.03	81%	15%
The LCA lab made me more aware about how design choices have global economic impacts	4.42	96%	4%

The LCA lab made me more aware about how deign choices have global environmental impacts	4.38	96%	4%
The LCA lab was a waste of my time.	1.69	4%	8%

Table III shows the results to LCA survey question 4 which asks students to evaluate their level of attainment of the ABET student learning outcomes SLO2 and SLO4 which both speak to placing engineering designs in a broader context. As this is a sophomore level course (and most students indicated they had not been exposed to LCA before), it makes sense that most students felt they were introduced to or developed these student learning outcomes through the LCA lab. It is also encouraging that the students who felt they 'mastered' these outcomes were also students who mentioned they had been exposed to the concept of LCA prior to this course. This result suggests that if we give students multiple exposure points to broader impacts of their engineering designs throughout the curriculum, more students will likely be able to feel they have mastered these desired learning outcomes.

TABLE III. LCA SURVEY RESULTS TO QUESTION #4 REGRADING LEVEL OF ATTAINMENT OF ABET STUDENT LEARNING OUTCOMES (SLO) 2 AND 4)

ABET SLO	%Introduce	%Develop	%Master
SLO2	38%	54%	8%
SLO4	38%	54%	8%

The open-ended responses to LCA survey question #5 (what was your main take-away from the lab) further emphasize the lab's ability to help students place their engineering designs into a broader context. From the representative responses below, you'll notice that students have an appreciation for economic and environmental design tradeoffs.

The breakdown of the individual impact of different portions of the component's life cycle on its overall environmental impact was one of the most interesting parts of this experiment. Visualizing the difference between the manufacturing and transportation made the economic justification of outsourcing production to China much more understandable than before. Without numerical data, the thought of transporting goods around the globe post-production seems wasteful simply to save on labor costs, but after taking a closer look at the true impacts of the different contributors, it becomes obvious why the push for recycling is so significant compared to a push for domestic production.

My main take away from the LCA lab was that as an engineer, solving a particular problem goes much further than simply solving the mathematical/analytic side of the problem. There is much more at play when you consider cost of materials and the life cycle of said materials. With all of these in mind, every engineering problem requires decisions to be made that will affect how affordable you project is and how renewable the materials you're using will be.

Often, one has to decide what matters more, being less wasteful for the environment or saving money. According to the information we were given, although the plastic track pieces create 10 times more CO2 and require 8 times more energy than the wood track pieces, the cheaper cost of production would unfortunately be the ultimate factor for many manufacturers. When money is not negligible and scarce, plastic track pieces are a more beneficial option. Larger and wealthier companies that have the capital to invest in the wood track pieces, however should do so.

I thought it was a great first lab! I love that the EE department is branching out into other areas to get a wide range of engineering experience. It combined EE environmental, and materials engineering aspects which I appreciated.

B. *Inclusive Design Reflection Results*

Figure 4 shows the result to the inclusive design survey questions 1-4. It is interesting to see that 89% of respondents (question 3) indicated they had never been personally affected by an inclusivity/accessibility issue with an engineered system likely due to the demographics of our student population in the college being predominately white and male. The fact that only 34% of respondents (question 2) indicated they were even aware of real-world products that excluded certain user groups and only 11% of respondents (question 4) had ever been asked to reflect on accessibility/inclusivity as a design metric prior to this course suggests that it is our responsibility to teach students about societal implications of their designs. It is encouraging that 55% of respondents (question 1) indicated that simply being asked to reflect on the inclusivity/accessibility of their design caused them to change their design process or modify their design in some way. This result suggests that if we can teach engineering students to think about who will be able or not able to use their end designs, students may be able to make design choices at the start of the design process that will enable their final prodcut to be accessible to a wider audience.

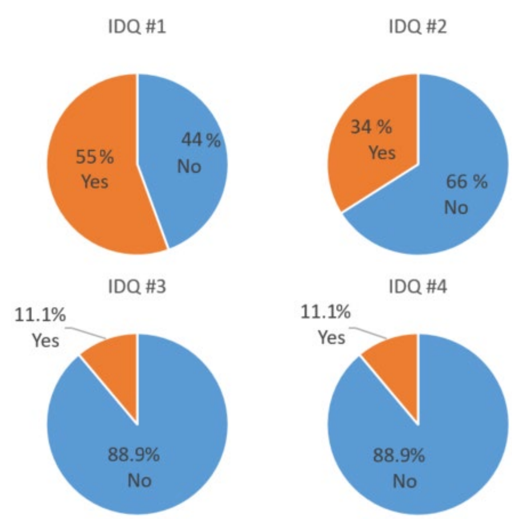


Figure 4. Results of Inclusive Design Survey Questions (IDQ) 1-4 (See section IV B for questions)

The open ended responses to inclusive design question #5 (What were your general impressions about being asked to reflect on the inclusivity/accessibly implications of your design) indicated that students valued the opportunity to consider societal implications of their designs.

I was glad to have that kind of importance placed on a worldly issue in a classroom setting.

Inclusivity is a key part in designing products for society

I thought it was a unique question and an important one to consider the answer to

VI. Conclusion

From the data, it is clear the LCA lab and inclusive design reflection helped students consider engineering designs in a broader context – whether economic, environmental, or societal. The data also suggest that the majority of the students who responded to the surveys had not been asked to make these design considerations in their prior coursework further emphasizing the importance of adding these topics early and often in the curriculum (and perhaps suggesting the need to add these topics into K-12 education). Finally, it was interesting to learn that students *appreciated* being asked to consider the effects of their designs in a broader context instead of solely focusing on the technical aspects of their work suggesting that students would likely welcome more of these type of activities in their engineering coursework.

As seen in the data regarding the mastery of SLO2 and SLO4, students cannot achieve mastery of learning outcomes if they are only introduced to a concept in one course. But if students experience activities that meet these outcomes in multiple courses throughout the curricula, they can hopefully achieve true mastery of the outcomes by the time they graduate.

It is our hope that this paper will give electrical and computer engineering faculty (and engineering faculty in general) concrete ideas on how to infuse engineering design in a broader context in their existing technical coursework so that students will have the opportunity to truly master these important 'broader context' ABET outcomes.

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