Incorporation of Corporate Social Responsibility into Problem-based Learning in a Semiconductor Device Course

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Introduction and Background

There have been frequent calls for fostering ethics and social responsibility among engineering students. Many of these efforts focus on personal behavior (or microethics) at the exclusion of broader, more structural concerns about the impact of professions, industries, and companies on a variety of stakeholders [1], [2]. The corporate context of most engineering work offers both opportunities and challenges when it comes to teaching students to engineer in a socially responsible way. At times, this centrality of corporate endeavors provides a front for students to not value or consider social responsibility, as they perceive the potential for impact within a corporate context to be limited. Unsurprisingly, students anticipate that, upon entering industry, their personal responsibility will be drowned out by corporate interests. In the face of such challenges, corporate social responsibility (CSR) provides a means of simultaneously conditioning our students to incorporate social considerations into their technical work and preparing them for work in a corporate setting.

This paper presents results from an effort to incorporate CSR into an undergraduate semiconductor device physics course using project based learning (PBL). It addresses two research questions:

> RQ1) How do undergraduate engineers account for CSR in their designs of semiconductor devices?
> RQ2) How does attention to CSR affect the ways in which students think about the ethical dimensions of their profession?

The engineering education research community has increasingly given attention to CSR, especially in the context of the extractive industries [3]-[6]. But little work has happened in other engineering disciplines. To our knowledge, this effort is the first time CSR has been explicitly incorporated into the semiconductors classroom.

We accomplished this integration using project-based learning (PBL), which provides a constructive avenue for authentic learning about the sociotechnical dimensions of engineering [7],[8]. In our project, we strove to meet the criteria for PBL laid out by the Buck Institute for Education [9].

We begin our paper by presenting the PBL assignment we designed and implemented in Fall 2018. In order to achieve the authenticity which is necessary for successful PBL [9], our assignment was vetted by two experts in the field of CSR. During the course of this work, we also collaborated with the instructor of a course on corporate social responsibility at our institution. Her students gave the semiconductors students feedback on drafts of their PBL final deliverables.

We then describe preliminary findings from the implementation of this assignment and new course design. To answer our first research question, we examine two sets of student work: a homework assignment which asked students to rewrite a prior homework problem so that it accounts for some aspect of CSR, and a deliverable for their final project in which they were expected to incorporate CSR into their design of a semiconductor device. To answer our second research question, we provide and analyze the pre- and post-course survey responses that assessed students' knowledge and opinions of CSR, including its place in their future careers. We conclude by offering preliminary assessments of how integrating CSR into student learning about semiconductors impacted student perceptions about the social responsibility of engineers and the engineering design processes.

Course and Institutional Context

We carried out this work at a small, engineering-focused public university in the Western United States. The university has approximately 5000 undergraduate students and 1300 graduate students. The Electrical Engineering Department, which is the primary focus of this work, graduates approximately 70 undergraduate students each year.

The course where the intervention took place is an undergraduate semiconductors elective course. This course is most students' first exposure to semiconductor physics and device design. Though primarily composed of undergraduate electrical engineering students, this course is also taken by students minoring in electrical engineering or students from related disciplines with an interest in semiconductors. Table 1 shows the demographics of the 35 students who enrolled in the course during Fall 2018, the semester in which this study took place.

Female	8	23%
Male	27	77%
Electrical engineering major	23	66%
Mechanical engineering major	7	20%
Computer science major	3	9%
Chemical engineering major	1	3%
Engineering physics major	1	3%
Junior	2	6%
Senior	33	94%
Transfer student	1	3%

Figure 1: The course was primarily composed of electrical engineering students, though also contained students from four other degree programs.

Course project and assessment

Best practices for successful PBL were used to incorporate CSR into this semiconductors course. To provide the authenticity which is required of high-quality PBL [9], two guest speakers were invited to talk to the students in the first few weeks of the course. One speaker was an engineer working in industry as a manager of social responsibility and sustainability initiatives for a large technology company. The second was Jessica Smith, a co-author on this paper who publishes widely on the intersection of engineering and corporate social responsibility, including in engineering education.

The final project was conceptualized by the two authors of this paper. The industry expert who spoke in the class provided feedback on the project and its assignments to provide authenticity in the project. The project was introduced to the students during the fourth week of the semester. Students were informed that they would be working on teams as employees of a company named Peach Inc. They were tasked with proposing a design for a semiconductor device of interest to Peach. Due to Peach's recent interest in CSR, they were also expected to account for CSR considerations in every technical design proposed by their team.

The students were informed that their projects needed to meet the following learning objectives:

- **Explain the relationship** between a semiconductor technology and one dimension of social responsibility (e.g. labor, manufacturing practices and the environment, mining, social impacts of technology, energy consumption)
- **Define** clear, achievable objectives for the development of a semiconductor device, **articulate** how these objectives are informed by CSR considerations, and **develop sufficient criteria** for assessing your design
- **Integrate social and technical considerations** into your **design** of a semiconductor device for sale by a corporation
- **Justify** their work to multiple external audiences

There were three project deliverables that were turned in during the final week of the semester. These included a design memo written to an engineering manager, a summary of their work to be included in the company's annual CSR report or website, and a presentation to Peach's Board of Directors. The design memo needed to introduce the device and the motivation for its design, state the objectives of the design, and present the final design using diagrams, tables, and text. One or more CSR considerations needed to be explicitly and clearly accounted for and integrated into their design. Then, in their draft CSR report, the students were tasked with summarizing – for a broad audience—how they accounted for CSR in their design. They were also expected to write a 1-2 paragraph reflection of how incorporating CSR influenced their design process and final design, because reflection is another suggested component of PBL [9]. Finally, they had to give a short in-class presentation to Peach's Board of directors justifying their design and the incorporation of CSR.

Over the course of the semester, the students were expected to submit a project proposal, meet with the course instructor during office hours to discuss their progress, and bring in drafts of their two written deliverables for peer feedback. They received feedback on their design memos from other students in the semiconductors course. Their CSR summaries received feedback from students taking the *Corporate Social Responsibility* course that same semester. The course is an elective that fulfills the humanities and social science graduation requirements for undergraduates. It primarily draws on social science research to develop students' critical thinking skills about CSR.

Appendix A contains the complete project assignment document.

CSR was also incorporated into the semiconductors course in other, less-intensive ways throughout the semester. These included an assignment to rewrite a homework problem to account for some aspect of CSR (see the *Analysis* section below for results from this assignment), in-class discussions, and excerpts from a documentary focused on waste and labor issues in the electronics industry [10].

Analysis

To answer our research questions, we used two methods to gauge how students' knowledge, opinions, and skills surrounding CSR changed over the course of the semester: analyzing student work and comparing students' pre-course and post-course responses to a quantitative survey.

Accounting for corporate social responsibility in semiconductor device design

Our first research question was: *How do undergraduate engineers account for CSR in their designs of semiconductor devices?* To address this question, we examined two pieces of student work: an assignment in which they were tasked with rewriting a homework problem to account for CSR and the final project written deliverables.

For the problem rewrite, students were asked to do the following:

> Select one of the problems from this homework and rewrite it so that it accounts for CSR concepts or considerations. Then, write a solution to your problem.

The two written project deliverables were described in detail in the section above.

From these samples of student work, a number of findings emerged related to students' perceptions of where social responsibility issues emerge in a corporate context; the types of social responsibility issues that were considered; and the degree to which social responsibility considerations were (or were not) integrated into the students' problem definition and problem solving. These will each be described in greater detail now.

Students possessed a range of ideas about **how social responsibility is accounted for in a corporate setting**. In the problem rewrite assignment, students occasionally referenced a chain of command, with the implied expectations from superiors ("Say you were asked to source some Si [silicon] for this semiconductor." "Your job is to…"). Others referenced supply chain considerations ("In order to obtain these materials, however, you must purchase them from one of two suppliers."). A few discussed the responsibilities that come with being an engineer in a corporate setting ("Additional safety precautions for workers must be accounted for.").

In their final project deliverables, the corporate structure was expressly a part of the assignment, and thus it was harder to draw conclusions about the students' perceptions of how CSR might be incorporated into such a setting. However, a few groups communicated ideas which engaged with the corporate setting beyond the expectations of the assignment by, for example, referencing international standards for health and labor. One group laid out steps to determine the source of their materials, which included, "Sending mandatory survey responses to suppliers that are based off of the Conflict Minerals Reporting Template created by the Electronic Industry Citizenship Coalition (EICC) and the Global e-Sustainability Initiative (GeSI)," and, "Establishing new term and conditions in the contracts of present and future suppliers that stipulate responses to conflict mineral related inquiries." They gleaned these suggestions from a government conflict minerals report [11].

A few groups specifically acknowledged the roles and responsibilities of practicing engineers and engineering firms when it comes to social responsibility, which was an interesting result. One group summarized the company's responsibility, "to act in a manner that protects the welfare of the public and the environment." Another very thoughtfully laid out what they saw as the role of engineers and the mindsets of engineering:

> It has become apparent that the engineers of companies definitely shoulder the weight of some of responsibility (sic). It stands to reason that getting more than just the engineers involved in some of these decisions would be beneficial, but it is absolutely crucial that engineers be a part of this process. Afterall, the goal of an engineer is problem solving, and using that skill in this area could prove to be very helpful.

Another interesting finding was the **types of social responsibility considerations** that students chose to focus on. For the problem rewrite assignment, a little over half of the students sampled (8 out of 15) incorporated questions related to the sourcing of materials, production waste and/or recycling materials, and/or labor practices. The remaining students tackled very diverse issues, ranging from the personal responsibility to share (or not to share) technical knowledge which could lead to technologies like an atomic bomb, to microethical questions like what to do when faced with evidence of falsified data. A few students raised concerns about what to do when a supplier was behaving questionably.

One of the most interesting responses wrestled with the social justice tradeoffs of a certain technology. The student wrote a problem which provided cost information on two different materials, and asked which would be preferred in a high-speed computing environment. In their proposed solution, the student described the tradeoffs between performance and product affordability. She then wrote, "If the product is necessary for many people to acquire at a low price, spending more time redesigning the system to accommodate lower frequency Si (silicon) processors may be the better choice for overall product affordability and employer profitability due to decreased production costs and increased sales."

On their final projects, the students again largely focused on issues of materials sourcing and production waste/recycling. There were fewer references to labor concerns than in the problem rewrites, though one group proposed selecting a material for the reason that it could be mined responsibly entirely within the United States ("When operations take place in other countries with labor practice laws that are less strict, it can be difficult to ensure that the workers are not overworked and that they are safe. When choosing a company to source from we also looked specifically at companies that mine Boron because it is used in our design."). Such a consideration was likely in response to one of our guest speakers, whose expertise is on improving working conditions within the high-tech industry.

Our last finding when assessing student work relates to **the degree to which students integrated (or failed to integrate) social responsibility into their problem defining and problem solving.** Our data for this comes almost exclusively from their final projects.

Interestingly, a few groups chose to focus their final projects on specific devices *because* of their perceived role in social responsibility (rather than weaving CSR into the design process after settling on a device). These included a group who selected thin-film photovoltaics because of its ability to reduce carbon emissions and two groups who worked on thermoelectric generators because they are used to recover waste heat from standard energy production methods.

In these projects, the students were assessed on whether the social considerations were integrated into their technical work, or were an afterthought. As a result, their writings largely reflected an effort to allow social responsibility to inform their technical decisions. For example, a group which designed high-temperature electronics wrote:

> Though both GaN [gallium nitride] and SiC [silicon carbide] meet the requirements, SiC will be used in the design due to it being less of a pollutant as well as not as dangerous to fabricate. GaN … can cause skin irritation and lung problems when breathed. Additionally, GaN is a bigger air pollutant. GaN offers higher mobility than SiC, but the environmental impacts of GaN outweigh this small bonus in device performance, so SiC is the prefered high bandgap material.

Approaches like the one above were common across the class. Another group thoughtfully summarized how accounting for CSR changed their design process:

> Instead of searching for ways to lessen the damage after the design was complete, we made CSR a priority from the beginning. This showed us just how much CSR can influence technical aspects of an engineering design. For example, non-toxicity was the number one requirement our semiconductor materials had to meet. Therefore, a CSR consideration heavily influenced what materials were possible for us to use while meeting the requirements we had set. Finding things like bandgap and lattice structure were secondary priorities, where they might have been of higher priority had we not considered CSR first.

Ethical dimensions of engineering work

Our second research question asked: *How does attention to CSR affect the ways in which students think about the ethical dimensions of their profession?*

To assess how students' knowledge, abilities, and opinions about CSR and engineering changed (or did not change) as a result of the CSR-focused project, we administered an assessment survey at the beginning of the course and the end of the course. The survey was developed by one of the authors with the assistance of expert panels of practicing engineers and engineering educators and talk-alouds with students and is described at length in other publications [6].

	Highest importance			When possible			Not important			I don't know	
	Pre	Post		Pre	Post		Pre	Post		Pre	Post
Their shareholders	49%	43%		40%	43%		0%	11%		11%	4%
Their employees	**63%**	**71%**		**31%**	**29%**		**0%**	**0%**		**6%**	**0%**
Communities affected by their business	**66%**	**86%**		**31%**	**14%**		**0%**	**0%**		**3%**	**0%**
Society at large	46%	50%		49%	46%		0%	4%		6%	0%
Suppliers and contractors	**34%**	**46%**		**43%**	**39%**		**17%**	**14%**		**6%**	**0%**
Customers of their products	54%	50%		34%	43%		6%	7%		6%	0%
Government agencies	26%	32%		57%	61%		11%	7%		6%	0%
Activists opposed to their industry	31%	25%		51%	64%		14%	11%		3%	0%
Future generations	66%	61%		29%	32%		0%	4%		6%	4%

Figure 2: Student assessment of the importance of a variety of stakeholders. Note that the bolded figures are discussed further in the text.

The semiconductors students showed the most significant changes in how they thought about stakeholders. First, they broadened their understanding of a technology's stakeholders to include employees, communities impacted by their business, and suppliers and subcontractors (see bolded data in Figure 1). The largest increase was in "communities affected by their business," which went from 66% of students ranking them "highest importance in the pre-survey to 86% in the post-survey.

The students also showed an increase in their belief that they would have to identify relevant stakeholders as a part of their future careers as engineers (Figure 2). Almost all students (93%) ended the course expressing a belief that engineers played a role in a company's CSR efforts, up from 80% of students believing so at the beginning of the course.

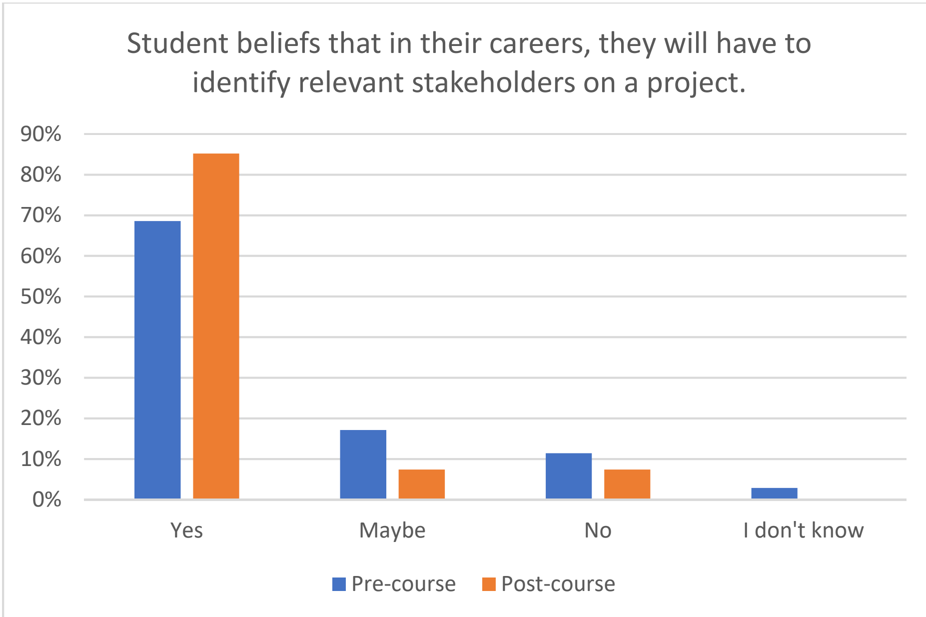

Figure 3: Student beliefs about stakeholder identification in their careers as engineers

The students also expanded their understanding of corporate interests to include social responsibility, specifically safety, environmental performance, and positive reputation among both society in general and stakeholders (see the bolded data in Figure 4). The significance of stakeholders in student learning is evident in the jump from 80% of students ranking "positive reputation among stakeholders" as "very important" in the pre-survey to 96% of them doing so in the post-survey.

Company concern	Very Important			Somewhat important			Not important			I don't know	
	Pre	Post		Pre	Post		Pre	Post		Pre	Post
Health of local communities	34%	50%		51%	50%		11%	0%		3%	0%
Economic development of communities	40%	39%		51%	57%		9%	4%		0%	0%
Safety of industrial processes	**63%**	**86%**		**31%**	11%		**6%**	**4%**		**0%**	**0%**
Security	89%	89%		11%	**11%**		0%	9%		0%	0%
Environmental performance	**37%**	**50%**		**57%**	50%		**6%**	**9%**		**0%**	**0%**
Positive reputation in society	**49%**	**57%**		**46%**	**36%**		**6%**	**7%**		**0%**	**0%**
Positive reputation among stakeholders	**80%**	**96%**		**17%**	4%		**0%**	**0%**		**3%**	**0%**
Relationship with local government	37%	39%		54%	**61%**		6%	0%		3%	0%
Profit	83%	79%		17%	21%		0%	0%		0%	0%

Figure 4: Student perceptions of corporate priorities

The survey did not, however, reveal significant changes in how students viewed the importance of the ethical dimensions of engineering for their future career, perhaps because they began the course with already high importance place on ethics: 89% viewed ethics as "very" or "somewhat" important at the beginning, whereas 93% did so at the end.

Finally, the students ended the course with stronger beliefs that group projects were effective for enhancing their learning (Figure 4). Seventy-eight percent ended the semester believing that they were very effective or somewhat effective, up from 67% at the beginning of the semester.

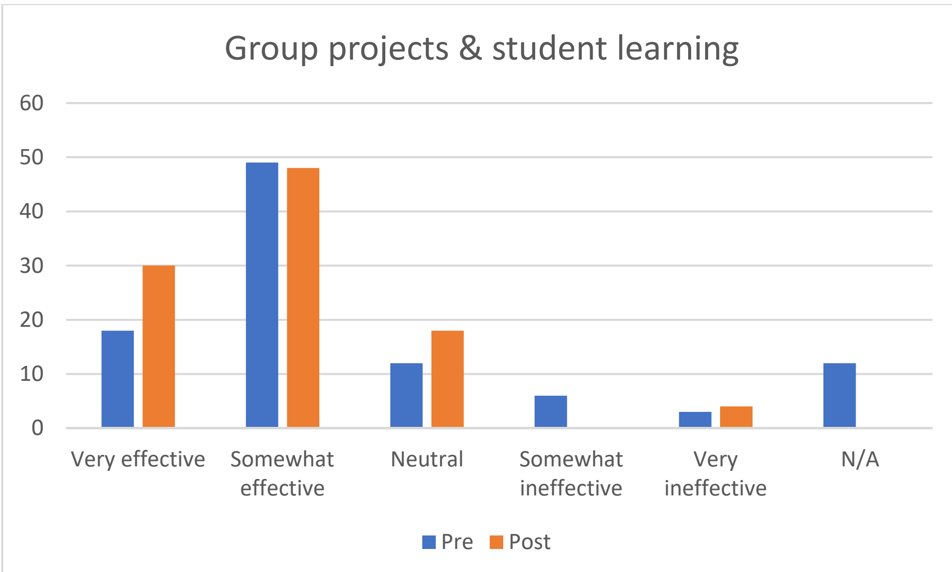

Figure 5: Student assessment of group project contributing to their learning

Discussion and Conclusion

Our class project on CSR in the semiconductors course suggests that it was especially effective for broadening students' perceptions of relevant stakeholders and company priorities. Students also ended the semester more likely to view stakeholder identification as a part of their careers as engineers, and many of them successfully integrated wider concerns surrounding social responsibility – particularly as it related to supply chains –into the problem rewrite and final project deliverables. Together, these results suggest that the students broadened their perceptions of the engineering profession to encompass the social concerns that many engineers find to be valuable in their careers, but lacking in their undergraduate training. For example, Trevelyan's 2014 research – which included interviews with more than 300 practicing engineers, surveys of an additional 400 more engineers, and participant-observation with engineers – found that the engineers who had persisted in the profession for a decade or more had "realized that the real intellectual challenges in engineering involve people and technical issues simultaneously. Most had found working with these challenges far more satisfying than remaining entirely in the technical domain of objects" (quoted in [2]).

In addition to refining students' views on social responsibility, the final project assigned here managed to develop other professional skills which, though not specific learning objectives of the class, we also considered positive achievements. These were specifically in the area of communicating complex concepts to a non-technical audience. This skill was demonstrated in the group's CSR reports, which they were supposed to write for public understanding. A few groups did this particularly well, taking pains to explain ideas like efficiency and clearly motivating their work in such a way that the public might appreciate its significance.

One of the most interesting findings from our research was how the students approached the tradeoffs that are usually necessary in this work – and really in all engineering work. A few groups tried to sell their device as a win-win, with no clear drawbacks: "This would not only be a profitable venture for Peach [the fictional company which was the focus of the final project], but it works to satisfy the company's responsibility as an engineering firm to act in a manner that protects the welfare of the public and the environment." Though such a situation is possible, it is unlikely that a single engineering solution would truly satisfy all involved. Other groups did acknowledge the necessity of such tradeoffs. For example, one wrote about their LED (light-emitting diode) design:

> All these factors suddenly make design choices much more difficult to make with pros and cons for all materials. In our specific design, the semiconductor materials we chose were not the top performers in terms of lumens per watt, but instead, they featured less harmful chemicals involved in manufacturing.

Another group reflected on the project as a whole, and its impact on how they perceive engineering practice:

> It was evident from the beginning of the design process that fundamental incorporation of CSR considerations forced a trade-off of design efficiency. This is redolent of the nature of engineering design. One cannot have the best of all worlds, it is likely any discrete design choice will have a resounding impact on the device as a whole. From our experience, incorporating CSR often increases design challenges, and in turn the cost of development. Thus, it is the responsibility of the company to weigh the costs of CSR incorporation in design against the net gain to society. Our team strongly believes the reduction in efficiency due to use of sustainable materials is a net gain for both Peach Inc. and its stakeholders.

In future offerings of the course, we intend to build on our initial work by improving the final step of PBL, which is authentic reflection on the process. Some of the groups that we looked at did very thoughtfully reflect on points such as how this assignment and course altered their perceptions of engineering practice, and how their team carried out the design process to account for CSR. However, most team reflections were superficial and vague, at best, a result we have also seen in past work incorporating reflection into engineering courses [12]. We plan to provide better guidance to the students moving forward on what high-quality reflections look like. We also will work to weave CSR more completely throughout the semester. A few students observed on the end-of-semester course evaluations that it was a focus at the beginning and end of the course, but was not given much attention at other times. We agree with this assessment, and will take steps to integrate it more into other course assessments and in-class time.

We hope that this work will broaden the space for the types of industries and engineering work where CSR is accounted for in the engineering classroom. We believe that if students are exposed to the challenges and benefits of accounting for social responsibility in their engineering work, they will be better equipped upon entering the workplace to engage with such problems.

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Appendix A – Final Project Assignment

EENG 421: Semiconductor Device Physics and Design – Final Project

Fall 2018

Introduction

You are working on a team of three engineers and scientists at Peach Inc. You are tasked with proposing a semiconductor device design for one of the applications below which is of interest to this very diverse company.

Peach has recently increased its attention to Corporate Social Responsibility (CSR). This is in response to recent demands from customers and employees after public exposure of a CSR issue. As a design engineer, you are now expected to account for and incorporate CSR considerations into every technical design proposed by your team.

Learning Objectives- A successful project will demonstrate the following abilities:

- **Explain the relationship** between a semiconductor technology and one dimension of social responsibility (e.g. labor, manufacturing practices and the environment, mining, social impacts of technology, energy consumption)
- **Define** clear, achievable objectives for the development of a semiconductor device, **articulate** how these objectives are informed by CSR considerations, and **develop sufficient criteria** for assessing your design
- **Integrate social and technical considerations** into your **design** of a semiconductor device for sale by a corporation
- **Justify** your work to multiple external audiences

Applications of Interest to Peach Inc.:

- Power transistor
- Charge-coupled device (CCD) cameras
- LED displays
- Solid-state lighting
- Micro-electro-mechanical systems (MEMS) sensor
- High-temperature computing
- Advanced photovoltaic design (beyond a crystalline Si-based pn junction)
- You can propose an additional application to your engineering manager, [Instructor], if there is another interest your team finds promising.

Potential CSR considerations:

- Materials/mining
- Manufacturing and recycling
- Labor practices
- Power consumption
- Social impacts of computing
- Other relevant issues

Formative Deliverables (only graded for completion)

October 5 – Project proposal due via email submission. Your proposal should consist of one paragraph which includes: The application/device you plan to design; the dimension(s) of CSR that you will investigate and incorporate into your design; preliminary ideas for your design; at least three references you plan to reference as you work on your project (you will likely need a lot more than three by the time you submit your final deliverables!). One proposal per group.

Week of November 5 – Plan a 15 minute window when your group can come by [Instructor]'s office hours for a quick check-in on your project progress.

November 26 – Each group should bring three copies of a completed draft of Deliverables #1 and #2 (see "Design Memo" below) to class for peer feedback.

Final Deliverables

You are responsible for three deliverables. #1 and 2 are to be turned in on the day of your presentation (#3).

1) 3 page design memo to engineering managers

Your design memo should consist of the following sections, with complete citations for any references you use. Write your memo to an audience of engineering managers who share your background in EENG 421.

> In 1-2 paragraphs, explain the need for your device, its basic operation and use, and a relevant overview of its design.
>
> State the objectives of your design at the start of this section. (Are you designing for switching speed? Low cost? A certain wavelength of emission? Use of a certain material?)
>
> Then, present your design using diagrams, tables, graphs and text. Be sure to specify any parameters you can (material(s), dimensions, doping, etc.) and use citations and/or calculations to support your choices.
>
> One (or more) social/CSR considerations should be explicitly and clearly accounted for and integrated into your design. For example, did you change your material choice? Or emphasize one design parameter over another? These sociotechnical choices should be explicitly described and justified, but integrated into the technical decisions that you make.

2) 2 page summary to be included in the company's CSR report or website

Write a 2 page summary of how you accounted for CSR in your design. You summary will be included in Peach Inc.'s annual CSR report and posted on its website. Because of this, it should be written to a broad audience of prospective customers and the general public.

In your summary, you should focus on a single dimension of social responsibility as it relates to your application and design.

You should model your work after the some of the CSR reports you have read this semester. Use citations to support any claims, and give credit for any images you use. Your report will be read by a group of external CSR consultants, who will give you feedback on a draft version (due November 26).

In addition, spend 1-2 paragraphs reflecting on how incorporating CSR considerations influenced your design process and final design. Write this reflection as a separate section. Your manager will read it for your annual performance evaluation.

3) Presentation to Peach's Board of Directors

Your team will present for 6 minutes (plus 1 minute of questions) to Peach's Board of Directors, which includes technical experts, CSR professionals, and shareholders focused on maximizing profit. The goal of this type of presentations to executives is to demonstrate cost savings to the brand. When an employee demonstrates significant value added to a company then they have an opportunity for a higher level or more strategic position or other financial rewards.

Your presentation should be structured as follows:

2 slides: Introduction to your application

1 slide: Overview of pertinent design parameters

1 slide: Overview of how you accounted for CSR in your design

1 slide: Justification of your work with respect to the company's motives and goals. This could include an argument such as:

- How the integration of CSR prevented or mitigated supply chain operational and company reputational risk (company cost reduction)
- How ensuring sound social and environmental responsibility practices can ultimately reduce cost to the company (e.g. labor efficiencies (less worker turnover, etc.), good health & safety practices (no worker injuries, etc)., avoiding conflict minerals to ensure a secure supply chain)
- Or another stance you can articulate