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# Sustainability designation, introductory course, and a new textbook in an engineering curriculum

**Jeremy Vanantwerp, Calvin University**

Professor of Engineering at Calvin College.

**Ms. Julie Anne Field Wildschut, Calvin University**

Julie Anne Wildschut is an assistant professor in the Engineering Department. Her research interests include various aspects of sustainability including improving access to clean drinking water, reducing human impacts to waterways, and designing a more sustainable built environment.

**Matthew Heun, Calvin University**

## Sustainability designation, introductory course, and a new textbook in an engineering curriculum

Sustainability is an important topic. If human societies don't live sustainably, by definition, we will experience drastic reductions in our population and/or standard of living and may cease to exist. Knowledge about sustainability has become a foundational component of a general university education and of being an informed citizen. Sustainability, as a subject of study, is increasingly popular with students and is an increasingly relevant skill domain in the job market [1]. Given that undergraduate engineering curricula are typically very full of technical content, how is it possible to incorporate sustainability principles into an undergraduate engineering curriculum?

One approach, taken by several institutions of higher education, (e.g., [2]-[4]) is offer sustainability-related certificates; some are general certificates in sustainability studies while others focus on specialized topics. At 12–15 credits, such certificates would not typically fit into a four-year engineering program. Other institutions offer specialized sustainability-related certificates to working professionals in areas such as triple-bottom-line corporate reporting [5], design and construction of green buildings [6], and life cycle assessment [7]. However, these certificate programs are either too large (10 credits or more), or too technically specialized for most undergraduate engineering programs, or both.

In contrast, this paper describes a lightweight approach to incorporate sustainability education into engineering curricula. The intention is to complement engineers' technical knowledge and problem-solving skills with a sustainability mindset. The first part of this paper describes a sustainability *designation* for engineering majors. The second part of the paper describes the one-semester-hour seminar *course* that is the gateway to the designation. The third part of the paper describes the new *textbook* we developed to support the gateway course. Finally, the paper presents some future *developments* and takeaway *lessons*. Because curricular design and student experience are inextricably linked, we discuss both in this paper.

### I. Sustainability designation

The engineering sustainability designation, at Calvin University, was a response to the growing need for undergraduate engineering students to be exposed to concepts, principles, and responses to sustainability challenges. The designation was designed to fit within an already packed undergraduate engineering curriculum. Traditionally, an area of study or emphasis might be transcripted as a "major" or a "minor." However, most engineering students cannot add additional minors, which have minimum requirements equal to a semester (or more) of full-time coursework, without also extending their graduation timeline.

An alternative approach to teach sustainability content to engineering students would be to blend sustainability concepts and topics into existing engineering courses. However, there are two drawbacks to this approach. First is the difficulty in assuring common coverage and content in different engineering majors (disciplines). Each engineering major is already full of its own technical content. We wanted a simple-to-administer-and-implement approach that would be equally applicable to all engineering students at our institution. Second, the "micro-insertion"

approach is not clearly communicated to potential students and employers. We wanted a way to communicate to employers that a student who studies extra sustainability topics has completed the work. Seeing the sustainability designation on a student transcript indicates to future employers an interest in and proficiency with the concepts of sustainability. Also, we wanted to be able advertise *to students* the message "if you complete the requirements, you will receive visible recognition."

To earn the sustainability designation at Calvin University, students complete three or four courses (5–10 semester hours, total) and a sustainability-related practical experience. (In contrast, a minor is 6 courses or 18-24 semester hours.) These requirements are a minimum of two additional semester hours beyond the student's engineering major.

The sustainability designation requirements are:

a) A one-semester-hour Introduction to Sustainability Challenges seminar course, ENGR 184 (for details, see the next section).
b) A sustainability-related elective course of three or four semester hours. Typically, this course *also* fulfills another requirement in a student's engineering major. For instance, a sustainability-themed economics class would meet the requirement for the sustainability designation and also count for the engineering economics requirement.
c) A sustainability-related practical experience, such as an internship, a research experience, or a capstone design project. Typically, this requirement bears no credit load although it could be fulfilled within an engineering student's four-credit design class.
d) A one-semester-hour engineering Sustainability Analysis course, ENGR 384, which serves as an introduction to such topics as life cycle assessment, risk and hazards analysis, and applications of material flow analysis and societal energy analysis. (Note that a detailed discussion of this class falls outside the scope of this paper.)

This structure allows students from all engineering disciplines on our campus (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical) to earn the sustainability designation within an eight-semester engineering degree. Students apply to earn the sustainability engineering designation by compiling a dossier in the semester prior to their graduation. The students bear the burden of proof to show that they have earned the designation, and the dossier is the mechanism by which the students provide that proof. (See Appendix 1 for dossier requirements.)

The designation is administered by a faculty member in the engineering department, called the sustainability coordinator, who performs the following annual tasks:

- Communicate with instructors of the sustainability challenges course (ENGR184) to build a database of students who start the designation,
- Communicate with instructors of the sustainability analysis course (ENGR384) to collect draft sustainability designation dossiers from students.
- Collect and review final dossiers from students in the semester prior to their graduation.

- Monitor the list of approved elective courses for suitability. Propose the inclusion of new courses in the list as they arise.
- Submit a list of students who successfully completed the sustainability designation requirements to the registrar's office.
- Request from students and document their perceived benefits of the sustainability designation for job search and graduate school admissions processes.

When a student successfully demonstrates, through their dossier, that they have completed the designation requirements, a "designation" is added to the university transcript (see Figure 1 for an example).

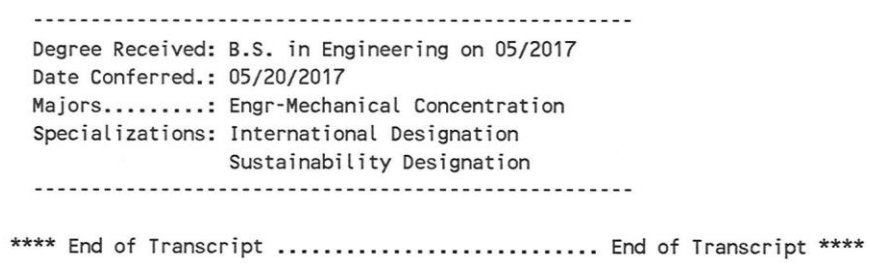


*Figure 1. Example transcript designation. The sustainability designation is shown on a student transcript, appearing as a "specialization" at the end of the transcript.*

### A. Success of the engineering sustainability designation 2017-2022

On average, 11% of graduating engineers obtained the designation over the first six years it was available (2017–2022); see Table 1. At our university, 10% of graduates earning the sustainability designation is sufficient to support one section each of the Sustainability Challenges (ENGR 184) course and the Sustainability Analysis (ENGR 384) course.

*Table 1. Sustainability designation graduation statistics.*

| Graduation Year | Students earning designation | Engineering graduates | Percentage of Engineering graduates earning designation |
|---|---|---|---|
| 2017 | 7 | 100 | 7 |
| 2018 | 9 | 89 | 10 |
| 2019 | 10 | 107 | 9 |
| 2020 | 8 | 84 | 10 |
| 2021 | 13 | 88 | 15 |
| 2022 | 14 | 82 | 17 |

Each year, graduating seniors who earned the sustainability designation are surveyed about the impact of the designation on their job search and future plans. Six of 16 students (38%) in the

first two graduating classes self-reported their post-graduate employment or graduate school placement was a direct result of their pursuit of the sustainability designation, a trend that has continued to the present time. Below are some quotes, older and more recent, from the student surveys. (Note that all student quotes in this paper are shared with students' permission.)

J. H. (2017 graduate) said,

> "I will be beginning my post-graduation career as an entry-level engineer [at a company that designs high-performing buildings with a focus on energy efficiency] in Seattle, WA, a job that came as a direct result of the sustainability designation. When I interviewed for this position, I was told that there were over 100 applicants for one position, and they were looking for someone memorable. After looking over my resume, the first question they asked was if I could explain what "a focus in sustainability" meant. They had never heard of a sustainability designation and were intrigued by the unique skillset I could bring. … They were impressed by the curriculum, and … [o]ne interviewer said, 'I wish I had *that* when I was in school.' I became memorable."

L. S. (2020 graduate) said,

> "As I look towards my life after graduation, I'm confident that the education I received inside and outside the classroom as part of the sustainability designation helped guide my career trajectory. … [M]y ultimate career aspirations are towards sustainability leadership in all of its facets—renewable energy generation and anti-racism and sustainability education. The sustainability designation gave me some of the technical tools in my 'toolbelt.' I've needed to engage with potential employers on sustainability issues, and the hands-on internship requirement has helped me to build professional connections that make me hopeful for my employment future."

P. S. (2020 graduate) said,

> "The sustainability designation gave me more tools for thinking about how to effectively manage resources in complex systems. Learning about LCA [life cycle analysis], MFA [material flow analysis], and I/O [input/output] accounting methods made me feel better prepared to enter any organization with a broader 'systems-thinking' perspective of sustainability. That systems thinking perspective can be applied to anything, really, including social problems."

The first offering of introduction to sustainability challenges course was in the Fall 2015 semester. Metrics for the engineering sustainability designation as a whole, such as participation and placement, indicated some positive results (for example, see above) but assessments of the learning outcomes for the introductory seminar class (see Table 2 below for learning outcomes and current assessment plan) also indicated some areas where we fell short of learning targets in the initial years of the designation. For instance, students' ability to describe sustainability was rather anemic.

For example, D.T. (2018) wrote in a final reflection paper (see Appendix 2):

> "Companies and Corporations [sic] should shift to using more renewable resources than nonrenewable sources, because of the large availability of the resources, the process to attain the energy doesn't harm the earth, and will provide the world with enough energy without the need to use dirty energy."

While a shift to renewable energy is laudable, this student's statements display a confusion of basic definitions and concepts (renewable vs. available; trading off different kinds of "harm," and whether it is possible to provide "enough" energy).

In addition, student engagement in, and enthusiasm for, the introductory seminar course seemed rather low. In response to course assessment and student evaluations, we revised the introduction to sustainability challenges course to be more engaging by pursuing a flipped-classroom model in following years (2019–present). The revised, flipped-classroom course is described in the next section and the new textbook to support the new class structure is described thereafter.

## II. Introduction to (revised) sustainability challenges seminar course

Sustainability Challenges (ENGR 184) is a one-semester-hour, gateway course that examines challenges associated with creating and maintaining a sustainable world in each of the three areas of sustainability: economic, social, and environmental. Using energy as the prime example, students learn about the complex, interconnected relationships and tradeoffs required to properly evaluate both collective and individual sustainability choices. The textbook (described in the next section) provides an outline and structure to the flipped course. Each week, students read a chapter, take a short online reading quiz, and respond to several discussion or project questions provided in the text. This format opens space in class for discussion of the weekly topic and perhaps additional teaching. Several projects provide additional learning, practice, and assessment throughout the semester.

Chapter readings introduce sustainability concepts and provide examples. For instance, the chapter on affluence defines terms such as wealth, consumption, and gross domestic product and presents the concept of economic metabolism. It describes the challenges of continual economic growth and considers alternative economic models. By the end of the chapter, students face the tension that growth in affluence, often socially desirable, also results in increased environmental impact. Similar learning and discovering is repeated with each chapter and each class session.

Students individually process the reading content in two ways. A short, online quiz containing, for instance, multiple choice and true/false questions provides some accountability for carefully reading each chapter and identifying key terms. Students also respond individually to several end-of-chapter discussion questions or projects. For the chapter on affluence, students are asked to consider what level of affluence is "enough" and why poverty exists alongside affluence. They research an example circular economy to determine if it really is sustainable. Many of these questions bring in human and economic perspectives on sustainability. Typically, these questions have no "right" answers. Rather, the questions, and discussions they engender, demonstrate the complexity of living sustainably and the importance of interdisciplinary solutions.

Class time is used for further teaching and group discussion. Short lectures review key terms, summarize main themes, or provide an additional example related to the chapter topic. Having prepared in advance, students arrive ready for discussion of complex topics in class. Discussion groups are formed in a variety of ways, including by student preference, around a topic of interest, or randomly. Group size also varies to provide learning spaces for different preferences.

*Table 2. Introduction to Sustainability Challenges student learning outcomes (SLOs). Third column is the number of individuals (or groups) out of the total that met the SLO in fall 2022.*

| SLO (numeral) and assessment rubric (subpoints) | Assessment location | Fall 2022 result |
|---|---|---|
| 1. Describe sustainability.<br>a. Demonstrated a complete understanding of the three pillars of sustainability and described how this impacts world ecosystems<br>b. Articulated sustainability challenges related to future work and professional responsibility | Project 4 | 21/26<br>25/26 |
| 2. Articulate how individual and collective actions relate to sustainability.<br>a. Described an individual, obtainable action for both "now" and "future"<br>b. Proposed three collective actions the university could take to make progress towards its sustainability goals | Project 4<br>Project 5 (Group Project) | 24/26<br>5/7 (groups) |
| 3. Identify sustainability interrelationships.<br>a. Described the social, economic, and environmental challenges associated with collective specific topic (related to University sustainability goals and chapters 6-10) | Project 3 (Introduced)<br>Project 5 (Reinforced) | 3/7 |
| 4. Demonstrate the need for interdisciplinary approach to sustainability. | Not assessed 2022 | |
| 5. Evaluate sustainable engineering practices and technologies.<br>a. Described tradeoffs for suggested collective actions.<br>b. Evaluated each suggested collective action using IPARX[1] framework. | Project 5 | 5/7<br>4/7 |

Student learning outcomes (SLOs) for the introductory sustainability challenges course are described in Table 2. Note that SLOs for the sustainability challenges course are *in addition to*

[1] The IPARX equation is a modified hybrid of the IPAT equation and Kaya identity, which is defined in the course textbook and used as a systematic framework for thinking about and evaluating sustainability.

learning outcomes of the engineering degree. Several projects that support SLOs for the sustainability challenges course and/or serve as assessment points for those outcomes are described below. Full project assignments are given in Appendix 2.

Comparison between the learning outcomes for ENGR184 and those of the Association for the Advancement of Sustainability in Higher Education (AASHE) Sustainability Tracking, Assessment, and Rating System (STARS) version 2.2 is instructive. The STARS website provides example student learning outcomes [8] that are "sustainability related" and "sustainability focused." For example, their first sustainability-focused learning outcome is "students will be able to define sustainability and identify major sustainability challenges," which corresponds to outcomes 1 and 3 in Table 2 above. However, unlike our outcome 2, which includes collective actions, the STARS outcomes are all focused on an individual perspective (arguably, with the exception of one related to "sustainable development").

For a thorough, modern (2022) review of sustainability-related student learning outcomes in engineering, see [9] and references therein. An older (2009) review of sustainability-related curricula in engineering is [10]. The paragraphs below describe the five projects in ENGR 184 and student learning results associated with them. (See Appendix 2 for full assignment details.)

**Project 1:** As an introduction to the course, students create an artifact representing their view and understanding of sustainability. Their work often displays a very limited understanding of sustainability at the outset of the course, such as recycling or planting trees, as seen in the examples shown in Figure 1. However, the project is a launching pad for expanding the definition of sustainability and highlights how each person's life experiences and values shape how they understand sustainability.


*Figure 1. Project 1 (Sustainability "lens" assignment). Three example student projects (clockwise from top left). Formed using found materials, "Second Chance" represents the idea of using things a second time to help the environment. The wooden shirt person relaxing in his "chair" highlights the tension between human convenience and leisure and the associated ecological depletion. The person depicted is oblivious of the melting Antarctic ice in the background (represented by blue paper). The light bulb represents the idea of recycling and*

**Project 2:** Students spend time in nature and behold ("connect with adoring receptivity") something for 30 seconds (an amount of time that seems incredibly short when read and incredibly long in practice). By slowing down, students are able to see and name at least one thing worth sustaining for its own sake. Several students referenced this assignment as pivotal in redefining and understanding sustainability.

For example, B. A. (2021) wrote in her final reflection:

> "What I liked about this task [(beholding)] was that I didn't just notice the pretty bush in nature and then walk by it, I stood there beholding it in time and finding myself admiring it. This led me to watch out for more aspects of nature that I admired. As I did this, I realized that my desire to care for the environment increased. I became more interested in sustainability and began to understand it better."

**Project 3:** Whereas students typically respond individually to 5–6 discussion questions a week, this project requires deeper research, in a group, on a single question/project from the textbook. Deeper research highlights the complexities of resource intensity and its interrelated challenges. Students summarize key points, different perspectives, and overall expected impacts in sustainability and share results with the class in a presentation. Several students credited this assignment as the point where they grasped the complexities of sustainability solutions more deeply.

For example, one group researched biofuels. "In theory, biofuels are carbon neutral," however, while "using biofuels lowers carbon emissions, we also produce carbon emissions in the process of making biofuels." The group highlighted the need for arable land to grow the required biomass for current consumption and economic implications of changing land use. They researched a farm using a biodigester to convert cow and hog manure into biodiesel for buses, trucks, and other heavy equipment. In the end, this group evaluated biofuels using the IPARX framework (see footnote 1 above) described in the textbook and concluded that since biofuels are insufficient to sustain the current population, the terms P and A (population and affluence) would decrease. They determined the R term (resource intensity of the economy) would go down, but X (the impact intensity of resource extraction and consumption) would remain about the same when considering the inputs to making biofuels. Overall, these changes to the PARX would drive the total impacts down. Although this analysis is simplified and uses the assumption that we would rely exclusively on biofuels for all energy needs, it demonstrates both (a) an understanding of the interrelated and complex aspects of sustainability and (b) a beginning of how to evaluate proposed sustainable actions. This was the students' first opportunity to apply the IPARX framework to a sustainability challenge.

The two remaining projects are an individual final reflection paper (**project 4**) and a group, in-class, oral presentation (**project 5**); see Appendix 2. As shown in Table 2, these two final projects are the point in the course where several of the student learning outcomes are assessed. In the 2022 final reflection (project 4), 21 of 26 students demonstrated an understanding of sustainability that included economic, social, and environmental aspects and 25 of 26 students articulated how sustainability challenges related to their future career. Some example responses follow.

D. M. (2022) pointed out the tradeoffs with different options related to material extraction, processing, and transportation of biomedical devices.

> "[M]oving the plant that makes the biomedical devices closer to the mines would decrease the transportation needed but might increase the amount of forest destroyed." Instead, increasing the efficiency of transportation could allow good to be processed in less environmentally impactul places while still lowering the overall impacts.

A. D. (2022) sees resource scarcity and social justice as two challenges related to his future career.

> "Robots aren't just metals. In fact, they contain a wide variety of materials in their construction. These materials come from many different sources and will vary in cost, environmental impact, and social values. When designing a robot, I will need to find a balance in the materials I am using between the three pillars of sustainability. I will need to ensure the robot is made from sustainable and ethically produced materials, while maintaining a certain budget to ensure the company I work for will actually be willing to purchase or manufacture the robot. Also, I will need to design the robot to perform its task ethically and not impede on any social values. Often, automation and robots are associated with replacing jobs in factories, as one specific example. While the robots are able to out-produce humans and make a more uniform assembly, they are taking jobs away from people with families and children, causing a harmful economic impact on them. I will need to ensure whatever I'm designing does not do that, or is only used for more dangerous jobs that could cost lives."

In the fall semester of 2022, 24 of 26 students listed one or more individual actions they could take as college students and as young professionals to live more sustainably. Some individual actions focused on ways to reduce vehicular carbon emissions by living on or near campus or carpooling to get groceries even when they don't have to. One student indicated a desire to be aware of current events to help them evaluate choices. Another wants to live in a smaller home located near work to reduce commuting impacts. A third student set a goal to own property and leave it as open space.

On project 4, 18 of 26 students were able to describe how their perspectives and understanding of sustainability changed throughout the semester using specific course examples and connecting back to their lens artifact (project 1). For example, B. A. (2022) said:

> "Another way that my perspective changed on sustainability was once I learned about the three aspects of sustainability. As mentioned before, I am a social work major so once I learned that sustainability has a social and economic aspect, and not just environmental, my view on what it is changed completely." For the lens assignment, "I created an earth because the environmental aspect was all I thought sustainability entailed. The picture from the book and class of the three aspects of sustainability in three circles overlapping in the middle, to which we find true sustainability is what stood out to me. This is when I understand the holistic approach needed to be sustainable."

Likewise, D. C. (2022) said:

> "My view on sustainability has widened and improved a ton as I now understand the sustainability factors of all aspects of our country and world. Before, I thought simply about emissions, deforestation, and increasing land use, but now I understand the picture is much wider than that, and almost everything is associated with another in some way." One example of this is problem shifting involving electrical vehicles, as described in chapter 8. "EV's [electric vehicles] have significantly lower carbon output depending on how the electricity is produced for them yet have drastically higher mineral depletion rates due to the resources needed to construct the batteries."

In project 5 (2022), 5 of 7 groups proposed at least three collective actions, 3 of 7 groups described the social, economic, and environmental challenges associated with those actions, 5 of 7 groups identified tradeoffs for the collective actions, and 4 of 7 groups evaluated the collective actions using the IPARX framework. Figure 2 shows two slides from a project 5 student presentation. One of this group's proposed ways to improve campus sustainability was to reduce the amount of space on campus that is "maintained land" (e.g., mowed grass) by returning the area to a "natural" state.

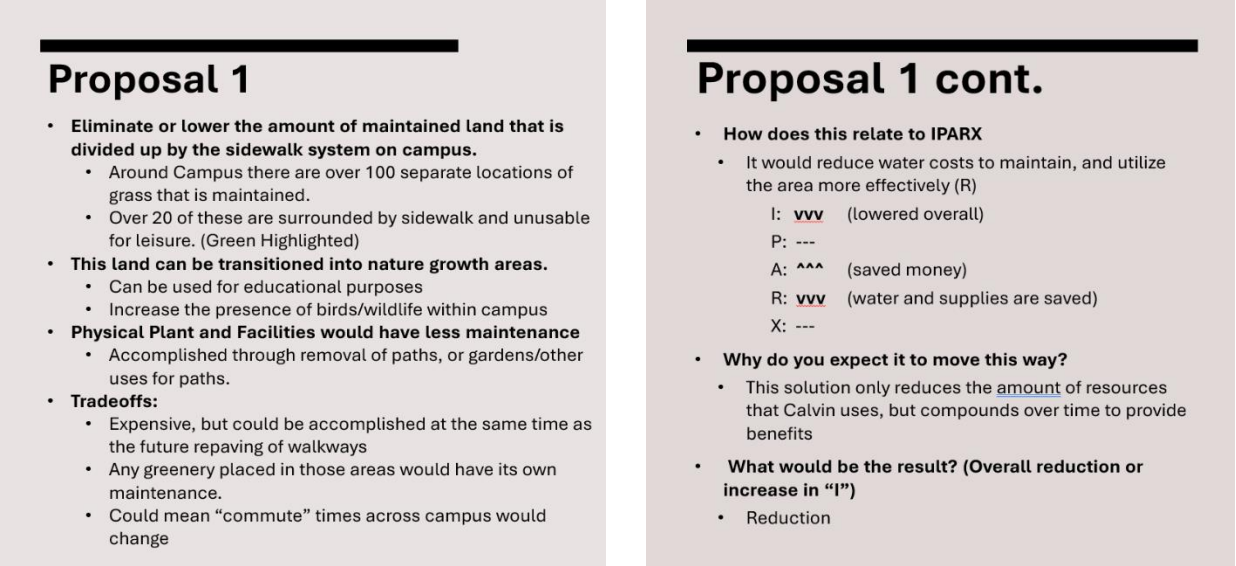


*Figure 2. Two slides from a student presentation showing a proposed campus sustainability solution and student evaluation of tradeoffs using the IPARX framework.*

Assessment results for project 5 indicate that most groups did not achieve the SLOs for outcomes 3 and 5. In project 4, students could individually demonstrate an understanding of the three pillars of sustainability, but in project 5, they did not connect the pillars to their group topic. It is unclear if the assessment for this outcome demonstrates an inability to apply the pillars to a specific situation or some other factor. Project 5 culminates in an oral presentation (see Appendix 2) but assessment of the SLO was based on a review of their submitted electronic materials. Students may have discussed the three pillars of sustainability during the presentation without necessarily including that specific content on their submitted materials. In future semesters, we may include a check box for outcomes 3 and 5 on the oral presentation grading

rubric. Additionally, the project assignment from 2022 includes excessive text that may have distracted students from intentionally displaying a connection to the three pillars of sustainability on their presentation slides. This will be clarified next time the course is offered for clearer communication of project expectations and slide content. An early design review could provide groups with the necessary guidance to achieve this and other SLOs. Additionally, 2 of 9 students shared that the combination of project 4 and 5 at the end of the semester was too much. Therefore, it is possible they did not put the right amount of effort into the project. Spacing out these projects may also increase learning.

**III. New textbook on sustainability**

When we were looking for a book (in 2018) to support the flipped-classroom version of the sustainability challenges course, we observed a gap in the available textbooks. Existing textbooks were either overly broad (e.g., [11], [12]) or were narrowly focused on one aspect of sustainability (e.g., [13], [14]). "Broad" textbooks appeal to a very wide audience and, therefore, have minimal technical content. These textbooks do not frame sustainability challenges and proposed solutions by critically and quantitatively evaluating technical and financial feasibility. Actually solving sustainability challenges requires first quantifying the magnitude of the challenge and then quantitatively evaluating the effectiveness of proposed solutions. (For example, replacing all coal-fired power plants in the United States (1.2 trillion kW-hrs/yr) with solar generation would require about 4 million acres of land (about 0.2% of the US land area, or about half the state of Maryland) and an investment of $2 trillion, which is about one tenth of the annual US GDP.)

On the other hand, texts with a narrow technical focus ignore the multifaceted, interconnected nature of sustainability challenges. For example, a text such as [13] doesn't address the way in which land use patterns, population, and transportation interact. Achieving sustainable transportation in the United States must include changing the scale at which local governments plan for and manage urban development.

Furthermore, we could not find any textbooks that provide discussion questions appropriate for a seminar-style overview course on sustainability. Existing sustainability textbooks provide quantitative technical homework problems and/or give "project-scope" assignments. We wanted a textbook that would provide a concrete basis for discussion of both "big-picture" questions and allow debate about the merits of specific policies or technologies, including technical as well as economic and political merits. In this sort of contextual discussion,

> students experience effective and emotional learning. The purpose of [which] is "to provide learners with clarity about their values and how they might start 'changing their mental models' in ways that will promote positive action [15]." [I]t is vital to include reflective learning spaces and opportunities for discussion and personal growth … unfortunately, … few engineering programs have implemented this approach resulting in a knowledge gap to determine the social influence in students' values, attitudes, and conceptions [9].

Therefore, we wrote a new textbook [16] that supports the flipped-classroom, discussion-style, seminar course structure we wanted. The book is arranged around a (vectorized) hybrid of the IPAT and Kaya identities that we call the IPARX equation; the impacts (I) of human activities are equal to the product of human population (P), affluence (A), the resource intensity of the economy (R), and the impact intensity of resource extraction and consumption (X).

The book is organized into three parts. Part I is comprised of Chapters 1–6. The first chapter is an introduction that lays out the IPARX equation as the central organizing framework for the text and the notions of weak and strong sustainability. Energy is introduced as the master resource. $CO_2$ emissions and anthropogenic climate change are the prime example of human impacts. The next five chapters each focus on one term in the IPARX equation: human impacts (*I*), population (*P*), affluence (*A*), resources (*R*), and the impact of resource extraction and consumption (*X*).

Part II (Chapters 7–10) explores the reasons why we face sustainability challenges in several topical areas: housing, transportation, agriculture, and land use. The areas selected are based, in part, on where energy (the master resource) is consumed.

Part III (Chapters 11–12) examines individual and collective actions for sustainability. By the end of the book, readers should see that sustainability entails important, urgent, and difficult challenges; that sustainability transitions are needed; and that everyone can play a role in helping the world become more sustainable through a variety of individual and collective actions. An authors' introduction to the book is available at [17] and a review of the book is available at [18].

We had several objectives for the textbook. First, to support the learning objectives for the course, the textbook has to convey basic information about sustainability in an easy-to-read and engaging way. We prioritize graphical presentation throughout, as a way to convey numerical data with a sense of scale and proportion. The textbook contains 66 figures across its 12 chapters. Several student survey responses (see below) indicate that we were successful in achieving this first goal.

Second, the textbook must stimulate classroom discussion to focus on tradeoffs and value judgements in policy questions about sustainability. The book has 188 discussion questions (average of 16 per chapter) to address the broad, interdisciplinary nature of sustainability challenges. Few, if any, questions have objective answers. Instead, they are true discussion questions that address moral, ethical, philosophical, and practical aspects of sustainability. We encapsulate the first two objectives for the book by saying that book is "easy to read but hard to digest." Students have to grapple with deep questions in meaningful ways. Again, many student responses to the question "what aspect of the course was most helpful to your learning?" pointed to in-class discussions provided by resources in the textbook (see below).

Third, the book supports further inquiry into sustainability with 98 project suggestions (average of 8 per chapter) that range in scope from a homework problem to a graduate thesis topic. Instructors can assign these as semester-long or capstone assignments (such as project 3, see Appendix 2), perhaps with in-class presentations.

Fourth, the book provides a cognitive framework for how to think about sustainability. The IPARX equation is the organizing principle for the first half of the book and is reinforced in the middle part by applications areas that illustrate how the different aspects of sustainability interact. The last two chapters (collective and individual actions for sustainability) are also organized around this perspective.

An anonymous end-of-semester survey asked students about several aspects of their learning in the Sustainability Challenges course (ENGR 184). Responding to "What aspects of this course most helped your learning?" several students in the fall of 2021 and 2022 commented favorably on the new textbook and classroom discussions:

- "The readings were probably the things that I learned the most." (2022)
- "The textbook was very guiding in breaking down the complexity behind sustainability and helped me better understand it." (2022)
- "I enjoyed the questions every week, it forced me to write and formulate thoughts on the applicability of engineering, which no other class really requires." (2021)
- "I think what helped me learn the most was when we discussed questions other than the assigned chapter problems, and/or when the professor gave her own mini-lecture on the topic." (2021)
- "Discussion based class time and listening to other perspectives is very good for learning." (2021)
- "The short lectures, discussions, research, and book helped me learn more about sustainability." (2021)
- "The in-class discussions most helped my learning. I grew to understand the nuances of many potential sustainability solutions through these discussions." (2021)
- "The group projects and writings." (2021)
- "Our class discussions and projects." (2022)

## IV. Results, conclusions, and further work

When the engineering sustainability designation was first proposed, our university Provost asked why the designation applied to engineering students only, the implication being students in every major across campus could benefit. The engineering faculty agreed, but designations were not available campus-wide in 2015. So, we embarked on a process whereby the engineering department would prototype the designation initially, with the goal to make a sustainability designation available campus wide, building on the experience of the engineering department. (In other words, we applied a typical engineering approach: rapid prototyping, testing, scale up.) At the time of writing this paper, a campus-wide sustainability designation has been approved.[2]

[2] The campus-wide sustainability designation is modeled after the engineering sustainability designation and will require the following courses: (a) Introduction to Sustainability Challenges (IDIS 184); (b) 8 additional semester-hours of sustainability-related courses, no more than 4 semester-hours from any one school; and (c) a 1 semester-hour Sustainability Experience course, necessary for transcripting a sustainability-related experience of 100 hours or more, such as an internship, a research experience, or a capstone project. When the campus-wide sustainability designation is approved, the engineering sustainability designation will be replaced by the campus-wide sustainability designation.

The intervening years (a) provided time to demonstrate a viable program structure, (b) were used to develop teaching and learning pedagogies for the designation courses (ENGR184 and 384), and (c) were used to provide sustainability education for interested engineering students.

An anonymous end-of-semester survey asked students about several aspects of their learning in the Sustainability Challenges course (ENGR 184). Responding to "What additional things could the instructor have done to enhance your learning?" several students in the fall of 2021 and 2022 requested more class or discussion time:

- "I feel like the class sessions should be longer (more like 1.5 hours) to accommodate more in-class teaching as well as the discussion." (2021)
- "Maybe do a variety more in class small group discussion or activities to challenge our opinions with others." (2021)
- "Informational lectures focused on teaching the concepts before having discussions would have been helpful for learning." (2022)

Motivated in part by these student comments, beginning next year (Fall 2023), the Sustainability Challenges course will become an interdisciplinary course (IDIS prefix instead of ENGR) and expanded from 1 to 2 semester hours. Already, approximately 15% of the students taking the engineering version were not engineering majors. Their insights into sustainability challenges are essential [9] because sustainability challenges will not be solved by engineering alone. The move from 1 semester hour to 2 semester hours will enhance the course by (a) enabling increased use of the questions provided in the textbook and (b) providing additional opportunities for student learning and deeper collaboration. For example, students enjoyed working in groups on project 3, but it took too much time along with other assignments. In a 2-SH course, project 3 will fit better. Additionally, the combination of weekly assignments and five projects exceeds typical expectations for a 1 SH course. On course evaluations, students indicated that they enjoyed the short lectures at the beginning of class as a way to set the stage for discussion. However, these lectures cut into discussion time, and there is time to discuss only 3–4 questions each week. Increased class time would allow for more discussion and perspective sharing as well as providing space for short lectures.

One quote from a 2022 project 4 submission shows how, by the end of the introductory course, this student recognized and embraced the many tensions inherent in our current sustainability challenges:

> "[This class] has been a great way for me to learn not only how I personally can be better at sustainability and live a more sustainable life, but it has also shown me how difficult it is. There are many, many categories when you talk about sustainability and sustainable living, and it isn't a one-size fits all. [It is] a holistic approach. It is the way every human being lives, it is the way our society functions, it's what we create our houses from, it's what we use in our houses, it's how we get from point A to point B, it's how much land we are taking, and there's just so much that even just being educated a little bit, I think can have a huge impact on the general population." (K.T. 2022)

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**Appendix 1**

## Student Instructions for Engineering Sustainability Designation Dossier

This document provides instructions for engineering students who wish to receive the sustainability designation to the engineering degree from Calvin University.

Students may earn the sustainability designation (e.g., "BSE Mechanical Concentration, Sustainability Designation") by completing all of the following:

(1) ENGR 184—Sustainability Challenges,
(2) a 3- or 4-semester hour sustainability-themed course,
(3) ENGR 384—Analysis of Sustainability Engineering Systems, and
(4) a sustainability-related practical experience such as an internship or ENGR340 project.

To receive the Sustainability Designation, students must prepare a dossier in the semester in which they complete the above four requirements. The contents of the dossier must be as follows:

- Completed Sustainability Designation Dossier worksheet (see following page)
- Copy of Academic Evaluation Record with the following highlighted:
    - ENGR184
    - 3-4 semester-hour sustainability-themed course (See note 1 below.)
    - ENGR384
- A one-page summary of their sustainability-related practical experience. Typically, this documentation will be a summary of the sustainability-related objectives of a senior design project or a letter from supervisor highlighting the sustainability-related aspects of an internship. (See note 2 below.)

Notes:

1. The 3–4 semester-hour sustainability-themed course will normally be taken from the following list of courses:
    - Sustainable Energy Systems (mechanical engineering senior special topics ENGR350 course)
    - Process safety and environmental protection (chemical engineering senior special topics ENGR350 course)
    - Global Health, Environment, and Sustainability (BIOL 364)
    - Environmental Chemistry (CHEM270)
    - Principles of Environmental Engineering (ENGR 306)
    - Sustainability Economics (ECON 232)
    - Economics of Energy and Sustainability (ECON233)
    - Human Impacts on the Environment (ENST 210)
    - Urban Planning for Sustainable Communities (GEOG 352)
    - Environmental History (HIST274)
    - Environmental Literature (ENGL305)

    If the 3-4 semester-hour sustainability-themed course is not from the list above, provide the course description and syllabus.
2. The one-page summary of a sustainability-related practical experience must include the following elements:
    - Description of the experience
    - An argument for how the experience is related to sustainability engineering, with reference to the University Statement on Sustainability
    - Demonstration of successful completion of the sustainability-related experience (e.g., grade in ENGR 340, letter from internship supervisor, etc.). If the practical

experience is not complete at the time of dossier submission, indicate expected completion date. (For example, a sustainability related senior design project will be completed at the end of the Spring semester.)

**Engineering Department**

**Worksheet for Sustainability Designation Dossier**

**Spring 2023**

Date: _____ Expected graduation date: _____

Student name: _____ Student number: _____

Email address: _____

Semester ENGR184 taken: _____ Grade earned in ENGR184: _____

Semester ENGR384 taken: _____ Grade earned in ENGR384: _____

Course number and title for
3-4 semester-hour sustainability-themed course: Grade earned:

_____ _____
(e.g., "ENGRW80: Sustainable Energy Systems")

One-line summary of sustainability-related practical experience:

_____

Attachments:

1. Copy of academic evaluation record with relevant courses highlighted
2. Course description and syllabus of 3–4 semester-hour sustainability-themed course (if necessary)
3. One-page summary of sustainability-related practical experience (typically, a letter from an internship supervisor or description of a senior design project)
4. Other documentation relevant to pursuit of the sustainability designation

**Appendix 2**

## ENGR 184 Project Assignments

### Project 1: Lens Assignment

***Overview:***

This activity involves creating/building an object to initiate student thought on different aspects and perspectives of sustainability. This activity will be done in groups of 2.

***Objectives:***

- Students will think about how they view sustainability and how it can be measured.
- Students will share and discuss this with another student.
- Students will build community as they articulate their view (lens) on sustainability and means of measurement using their artifact as a prop.

***Safety and building use:***

- Students will return all supplies and tools to the indicated workspace in the Engineering Building.
- Students will cut/create on at an appropriate table/space, not on the supply table.
- Students will wear eye protection when cutting with tools other than scissors.

***Time Expectations:***

- Approximately 60 minutes outside of class

***Assignment details:***

Issues of sustainability can be approached from many different aspects, perspectives, values, priorities, and with many different metrics. Everyone has a different set of life experiences that has shaped how they view the world including these issues of sustainability.

- Think about how you understand sustainability. What are your perspectives and values? How were these formed? What metrics do you use for issues of sustainability?
- Discuss these with your partner. What is similar about your understanding of sustainability? What aspects are different?
- **Together** (as a team of 2), create an artifact that:
    - Exhibits some of your shared values regarding sustainability OR that highlights your different perspectives.
    - Demonstrates or provides an example for one of the ways sustainability can be measured. (How sustainable is something? How do you quantify that?)
- Take several pictures of your artifact showing different perspectives. (Both students my use the same set of pictures.)
- **Individually**, write a paragraph that describes what you created and why.
- Upload your pictures (3) AND your personal paragraph to Moodle for grading.
- **Bring both the paragraph and artifact to class**.

***Supplies:***

Some materials and tools are available in the Engineering building workspace. Some additional tools may be available in the wood and metal shops. You may work on any of the wooden benches in the south end of the Engineering building. These are shared workspaces so please clean up after yourself and return unused supplies.

**Project 2: Liturgy of Land Assignment**

***Overview:***

This activity involves reading an article, traveling through the woods, and growing in awe of nature. They will be graded on a photo upload with a short description.

***Objectives:***

- Students will study the Book of Nature through immersion by traveling through the woods with intentional mindfulness, increasing their love of their creator.
- Students will behold something in nature.

***Safety:***

- While this is an individual assignment, you are welcome to take a walk with another student. Your pictures and observations should be individual.

***Time Expectations:***

- Approximately 60 minutes outside of class

***Assignment details:***

- Read the article *A Liturgy of Land and Call to Creation Connection*, by Richard Lindroth, (BioLogos), 2022.
- Take a walk through a natural area such as the nature preserver located on the east side of campus. As you walk, delight in nature and tune in to your senses.
- Behold (connect with adoring receptivity) some aspect of the natural world. As the author suggests, mindfully hold that connection for 30 seconds and as your do, engage with the wonder, awe, and worship it inspires.
- Take a picture of what you beheld. Upload this picture to Moodle with a short (2-5 sentence) description of how you engaged with it in wonder, awe, and worship.

***Reflect on these questions and be prepared to discuss them in class:***

- The article suggests that most people do not see the natural world around them because their minds and senses are not attuned to do so, that they have atrophied from lack of use. What keeps you from seeing (or hearing, tasting, feeling, or smelling) the natural world around you?
- How many trees can you identify by their leaves?
- The article suggests that Christians should be among the most appalled, the most grieved, the most concerned, the most intentionally proactive of all people with respect to environmental degradation. The author thinks this is because we are estranged from the

Book of Nature and have simplified and dutified the Book of Scripture. Why do you believe we are not?
- How does recycling reduce our understanding of our role in creation?
- How is nature-deficit disorder (the result of long-term estrangement from the natural world) disastrous to human society? (Think in terms of people, planet, and profits.)
- How is distancing ourselves from nature also distancing ourselves from God?

**Project 3: Contamination Intensity Group Share (Chapter 6)**

***Overview:***

This activity involves working in a group of 3-4 students to research a question from chapter 6 and prepare a short (<5 min) presentation/discussion.

***Objectives:***

- Students will be able to go deeper into one chapter question/topic.
- Students will be able to learn from peers about other topics.

***Time Expectations:***

- Approximately 60 minutes outside of class

***Assignment details:***

There are a lot of great questions presented in the back of Chapter 6 (Contamination Intensity of Resources) but you don't have time to fully research and respond to each one. Instead, students will work in small groups to just research one topic and then present their findings to the class. This can be followed by a few questions/comments. Below are the steps/details:

1) Sign up for your topic using the Moodle "Choice" activity (See Moodle "Assignments" section).
2) Read chapter 6 on your own.
3) Meet with your group to research your topic and prepare a short presentation. Use Google slides (with no theme) and **upload** slides to Moodle by **Wednesday by 3 pm.**
4) Google slides should include:
    a. Short description of the topic (background, definitions)
    b. Key points to consider when making a sustainable choice including 2-3 different perspectives related to sustainability challenges
    c. How this research relates to the IPARX equation[3]. Which variables increase or decrease by changing things related to your provided perspectives/key points?
    d. An ethical or discussion question for the class to consider.
5) Your instructor will compile the Google slides for the entire class and groups will take turns presenting their material.
6) Note: There are 6 groups, so each group only has 6 minutes to present and have some question time. Plan out your slides and timing. This is not a BIG assignment, but you should have discovered some good material to share.

[3] A modified hybrid of the IPAT equation and Kaya identity, which is defined in the course textbook and used as a systematic framework for thinking about and evaluating sustainability.

***Grading Items:***

- Students researched their topic, finding interesting perspectives and going beyond just a first "Google" search. Points will be awarded for each of the lettered items under #4 as well as on time completion.

**Project 4: Final Reflection Assignment**

***Overview:***

Individually, students will create a culminating deliverable on sustainability challenges drawing from several aspects of the course. Each deliverable will consider connections between sustainability, faith, and individual actions. **The deliverable may be an essay, a PowerPoint presentation, or a short video.**

***Objectives:***

- Sustainability and Faith.
    - Students will articulate their definition/understanding of sustainability.
    - Students will articulate sustainability challenges.
    - Students will make a theological case for sustainability. (Why, from a Christian perspective, should we care about sustainability?)
- Individual Action.
    - Students will describe how their "lens" of sustainability has changed from their initial lens project until now.
    - Students will include **two specific examples** of readings or activities that guided new understanding.
    - Students will commit to an individual sustainable action for "now" and sustainable action for the "future" (post-graduation).

***Time Expectations:***

- Approximately 2-3 hours.

***Assignment details:***

As discussed early in the semester, issues of sustainability can be approached from many different aspects, perspectives, values, priorities, and with many different metrics. Everyone has a different set of life experiences that has shaped how they view the world including these issues of sustainability. These perspectives, values, and priorities change over time, sometimes due to new experiences and sometimes due to increased learning.

This assignment requires you to write a personal statement of your view/definition of sustainability, a faith connection, and your plan of sustainable living. References from class materials, links, and discussions should support your points. Your deliverable should include/answer the following:

- **Write your personal definition of sustainability.** What is sustainability? Discuss not just environmental but also social and economic aspects.

- **Describe two sustainability challenges that overlap your possible future career/work.** Which of the sustainability challenges are most critical for your interests and possible future career? What interrelationships and tradeoffs exist around these challenges? What do you think are the most important ways technology can contribute to sustainability? What information do you need to know to evaluate these challenges?
- **Discuss how you see Christian faith relating to sustainability**. Answer the question, why should a Christian care about sustainability? You could consider Bible verses, Christian worldview/philosophy, confessions and creeds, design norms (for engineers), or other Christian writings. Note that you do not need to *be* a Christian or have a Christian worldview to answer this question. In any case, honest opinions are preferred.
- **Describe how your perspectives and lifestyle changed.** What stayed with you or struck you most from class this semester? How has your view or understanding of sustainability changed through this class? How have you changed your personal behavior in relation to sustainability challenges? What motivated this change? **Describe this using at least two specific examples of course content/activities/discussion that guided this change.** Make sure to connect this back to your first assignment where you created your lens on sustainability.
- **What does sustainability mean for how you will live your life?** Describe an individual sustainability action that you will integrate into your life now (as a college student) and something into your life in the future (after you are more settled into post-college life).

**Project 5: Final Exam Group Project/Presentation**

***Overview:***

**This project will help students answer the question "what can the University do today to be more sustainable?"** We have discussed a lot of sustainability challenges and how to evaluate them in this class. This final project will require research to describe and understand specific sustainability challenges and use the IPARX identity to evaluate possible actions so we can make more sustainable choices. Students will work in a group of 3-4 to research a component of the University's Statement on Sustainability, suggest collective action, evaluate action, and prepare a (15 min) presentation/discussion.

***Objectives:***

- Students will be able to deeply explore one topic/sustainability challenge.
- Students will be able to learn from peers about other topics.
- Students will use IPARX to evaluate the impacts to sustainability challenges and solutions.
- Students will use evaluation to suggest collective action for the University.

***Time Expectations:***

- Approximately 180 minutes outside of class

***Assignment details:***

- Read through the university's Statement on Sustainability. Notice it has 13 guidelines (teaching/research, purchasing/admin, solid waste/recycling, energy purchasing, water/wastewater, hazardous materials, transportation, food, campus grounds/land use, building construction, site planning, investment practices, outreach).
- Think about how these guidelines overlap some of the textbook sections (e.g., households, agriculture, transportation, land use).
- Form a group and identify guideline/topic for further research. Claim your topic on the course website.
- Identify the sustainability challenges associated with topic.
    - Include social, economic, environmental considerations.
    - Use the book, classroom discussions, and additional research to describe the complexities of your selected challenge as well as the potential community actions in the next step.
- Suggest three collective actions for the University to make progress towards sustainability goals and/or reduce negative impacts.
    - Describe who would follow through/oversee this action and who would benefit.
    - Describe tradeoffs (including time, cost, benefit, feasibility, . . .)
- Evaluate each suggested action using IPARX
    - Describe how each part of the IPARX identity would move (up or down).
    - Why do you expect it to move this way?
    - What would be the result? (Overall reduction or increase in "I")
- Based on your evaluation, what should the University do to be more sustainable?

***Formatting and Grading:***

- Each group member should contribute to research and writing on the project. However, groups should divide up some of the work among members.
- Presentations should be uploaded by 5 pm on the day they are due.
- Each member should present some portion of the project.
- Grading will be based on addressing each of the assignment details (as described above), the quality of research and analysis, and the quality and cohesiveness of the presentation.