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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29814

Designing for a Sustainable World: Integrating the United Nations Sustainable Development Goals into a First-Year Engineering Course in Science, Technology and Society

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Introduction

I am an instructor on a teaching team for a required first-year engineering course in science, technology and society (STS) at the University of Virginia. The course enrolls 360-400 students each semester, and its primary learning goals are to introduce students to social and ethical aspects of engineering design and to help them hone communication skills relevant to engineering practice. The major project in the course is a provisional patent application in which students describe a technological design they have developed in class. In previous semesters students would develop ideas for the patent application with relatively few parameters. They could generate ideas for nearly any kind of innovative technological device, process, service, or system as long as they could describe and illustrate it in 6-8 pages. It was thought that students would appreciate the opportunity in an STS course to work on a writing project that was more technically oriented and to develop their creativity by coming up with designs for new technologies that could help address practical everyday challenges students face.

These open-ended parameters, however, tended to hinder instead of inspire student engagement and creativity. The ideas students came up with were often trivial and unimaginative; they were frequently oriented toward individual use and addressed problems of no greater significance than that of minor inconvenience. For example, each semester would yield various designs for collapsible backpack umbrellas, automated erasers for dry-erase boards, and novel charging methods for personal electronic devices. Equally problematic was that students struggled to see the value of the patent application assignment to engineering practice. On course evaluations they frequently voiced that it was difficult to appreciate the project's relevance to a career in engineering especially as they were unlikely to become inventors or patent attorneys. Further, students had a hard time understanding how the patent assignment related to what they were learning in class lectures about social and ethical aspects of engineering design. As a consequence, students would often complain that the labs and lectures seemed like two distinct courses. How does writing a patent application for a portable backpack umbrella relate to the production of wine in ancient Greece and its use in social settings to indicate elite status? Because students had difficulty appreciating the value of the patent assignment specifically and STS more generally, they were less motivated to challenge themselves and invest in both the project and the course. But if the project could be revised in a way that would raise its stakes and require more explicit engagement with social and ethical dimensions of engineering design, then perhaps students would come to see the patent application, as well as the course itself, as making a more valuable contribution to their learning as first-year engineering undergraduates.

Drawing on scholarly methods for increasing the value students attribute to course goals and projects, I proposed reorienting the patent assignment specifically and the lectures more generally around the United Nations Sustainable Development Goals (SDGs) in order to augment students' perception of the course's value for their learning and professional development. I created a scenario for the course in which the United Nations had issued a

Request for Proposal (RFP) that invites engineering undergraduates to submit patent applications for technologies that could help their local university communities achieve one or more of the SDGs. Because the United Nations defines sustainability in social as well as more traditional environmental and economic terms [1], and many of the SDGs pertain directly or indirectly to matters of social justice and equity [2], to write the new patent assignment students would need to integrate practical technical expertise with an understanding of social and ethical aspects of engineering design. The new course scenario, then, coupled with the revised patent assignment, would help students appreciate the importance of integrating the practical and technical with the social and ethical. I also hoped it would help them see how projects undertaken in the course labs complement and build on themes addressed in the weekly lectures.

In what follows I elaborate how I developed the new patent assignment for a pilot Summer semester version of the course in 2019 and how it was later implemented in the main course in the Fall 2019 semester. I also explain how students at once welcomed and resisted working with the SDGs and the effects that reorienting the patent assignment around them had on their perception of the course's value. I conclude that both qualitative and quantitative data in student course evaluations suggest that reorienting course lectures and assignments around the SDGs played an important role in increasing students' appreciation of the course's contribution to engineering education and professional development.

A Review of Scholarship on Sustainable Development and Engineering Education

As the international conference on Engineering Education for Sustainable Development, now in its tenth year, attests, the past decade has seen a burgeoning of scholarly projects at the intersection of sustainable development and engineering education, often with reference to the efforts of the United Nations to promote sustainable development education and initiatives worldwide [3], [4]. Some scholars have taken a critical stance toward aspects of the UN SDG initiative, such as the anthropocentric concept of sustainability that underlies the Goals [5], [6] and the attenuated accountability measures for achieving them [7]. Among those endeavoring to introduce sustainability into engineering curricula, some instructors have had success using project-based learning in first-year engineering courses to promote broader awareness of sustainability concepts and concerns [8]. Scholars working specifically with integrating the UN SDGs into engineering education underscore the importance of incorporating learning modules on sustainable development early into core undergraduate courses. Their work also draws attention to the necessity of developing course activities and assignments that help engineering students appreciate a more capacious understanding of sustainability that includes environmental and economic as well as social and ethical domains.

In their 2018 article "Sustainability and Education for Sustainability: An Analysis of Publications from the Last Decade," Lucas Veiga Ávila and his colleagues analyze articles published from 2005 to 2014 on sustainability and education for sustainability in the Web of Science (WOS) database, which includes nearly 37,000 indexed journals, as well as an additional 17 articles published in January 2014 in a special edition of the *Journal of Cleaner Production* on "Higher Education for Sustainable Development: Emerging Areas" [9]. The authors position their study as a response to the United Nations Resolution 57/254, which called for a Decade of Education for Sustainable Development from 2005 to 2014 [9]. According to the United Nations

Educational, Scientific, and Cultural Organization (UNESCO), the Decade of Education for Sustainable Development had the following aim.

> The overall goal of the UN Decade of Education for Sustainable Development (DESD) was to integrate the principles, values and practices of sustainable development into all aspects of education and learning. This educational effort encouraged changes in behaviour [*sic*.] that created a more sustainable future in terms of environmental integrity, economic viability and a just society for present and future generations [10].

Elaborating on the significance of the UN's sustainability educational initiative for academic research, Veiga Ávila and his colleagues explain that because "education for sustainability is the path to global development, it is necessary to expand research and studies on the subject" [9]. Significantly, the authors highlight the important work that universities do "not only to generate and transfer relevant knowledge, but also to educate individuals and contribute to a more sustainable future" [9]. Importantly, at the outset of their study the authors note that they included not only environmental and economic but also social aspects of sustainable development in their study's purview [9].

After surveying 5,924 publications in the WOS database, the authors report that the highest number of publications in the areas of sustainability and education for sustainability came from the United States [9]. The study also identifies topics pertaining to engineering as well as education and educational research as among the most numerous [9]. Based on their findings, the authors conclude, "there is considerable growth in studies related to sustainability and education for sustainability issues, reflecting their importance to the fields of teaching and research, as well as for mobilizing society to embrace sustainable development [9]."

Below I briefly summarize two studies that follow on the trajectory mapped by Veiga Ávila and his colleagues. Both of these essays stress the importance of integrating learning modules on sustainable development into core courses in the first or second years of an engineering undergraduate curriculum. Their focus, however, is on integrating social and ethical analysis into technical courses in civil and environmental engineering and not into a course in STS dedicated to introducing students to such themes.

Angela R. Bielefeldt, in her article "Incorporating a Sustainability Module into First-Year Courses for Civil and Environmental Engineering Students" (2011), describes how two required one-credit first-year courses in civil and environmental engineering at the University of Colorado were revised to introduce students to sustainability [11]. Although sustainability concepts featured in upper-level required courses, they were not yet included in core first-year courses despite the importance that current students, alumni, and employers give to sustainability frameworks [11]. To address this deficit, learning modules on sustainability were introduced into required first-year courses in civil and environmental engineering. The learning goals of these courses included developing proficiencies in defining key aspects of sustainability and in explaining properties of sustainability and related scientific concepts pertinent to engineering practice [11]. After analyzing student responses to the new modules on sustainability in homework assignments and surveys, Bielefeldt concludes, "a simple course modification raised the awareness of engineering students about the importance of sustainability" [11]. Her study highlights the importance of using targeted homework assignments to introduce first-year engineering students to sustainability values and concepts.

In their 2018 essay "Engineering and Sustainability: The Challenge of Integrating Social and Ethical Issues into a Technical Course," Natasha A. Andrade and David Tomblin use stakeholder value mapping exercises to incorporate social and ethical approaches to sustainable development into a required second-year course in civil and environmental engineering at the University of Maryland [12]. Animating their endeavor is an awareness that, though the United Nations report *Our Common Future* defines sustainable development in environmental, economic, and social terms [1], engineering students often attend only to the environmental and, to a lesser degree, the economic. Overlooked are social and ethical dimensions of sustainable development [12]. To encourage students to engage in "macro-ethical and socio-technical thinking skills" the authors incorporated stakeholder value mapping exercises into the course curriculum [12]. Their goal was to help students appreciate "all three dimensions of sustainable development in a technical engineering course" [12]. After analyzing student performance in three classroom activities, the authors conclude that, though students became more proficient at identifying "social impacts," they "need more sustained exposure to socio-technical relationships throughout engineering curriculum to increase their sensitivity to and awareness of these relationships" [12]. Their work, then, draws attention to the importance of using course assignments early in an engineering curriculum to help students appreciate and attend to social and ethical in addition to environmental and economic aspects of sustainable development.

The instructors discussed above successfully integrated learning modules on sustainable development into required technical courses in civil and environmental engineering. My endeavor to reorient the patent assignment in STS 1500 around the SDGs builds on and extends the learning goals discussed in these studies by applying them to a non-technical engineering course in STS specifically devoted to introducing students to social and ethical aspects of engineering practice. Like these scholars, I hoped that aligning the course assignments with the United Nations' emphasis on education for sustainable development would increase the extent to which students value the inclusion of socio-technical and STS perspectives in core engineering courses they are required to take.

A Framework for Adding Value to Student Learning

Drawing on scholarly methods for adding value to student learning allowed me to reframe the patent assignment to better align with the learning goals of the course and to increase students' appreciation for how STS perspectives could contribute constructively to their intellectual and professional development as engineers. In their book *How Learning Works: Seven Research-Based Principles for Smart Teaching*, Susan A. Ambrose and her colleagues draw a direct correlation between student motivation and learning [13]. "When students find positive value in a learning goal or activity," they argue, "they are likely to be strongly motivated to learn" [13]. But the inverse also holds true. If students cannot see the relevance or importance of a course's content, then they will not appreciate its value and will not invest in developing the practices that facilitate effective learning [13]. The value students place on a course, then, directly affects their performance on assignments and activities. This means that an instructor's "fail[ure] to address students' perceived lack of value for a given task or goal" can contribute to patterns of evasion or rejection [13]. These patterns often lead students "to disengage from learning situations" or to commit only to "the minimum amount of work that is needed to just get by" [13].

In view of these challenges, Ambrose and her colleagues recommend several strategies designed "to increase the value that students place on the goals and activities" of a course [13]. Among them are connecting course materials to "issues that are important to students" and to "real-world event[s]" and the needs of "an actual client in the community" [13]. Common to these strategies is an emphasis on the real (or at least the simulation of reality). Reality conveys relevance, which in turn persuades students that a course is worth the investment of time and resources required to facilitate deep learning. It would seem, then, that reality and relevance go hand in hand, with one contributing to the other, in enhancing student perceptions of a course's value.

Below I describe how I leveraged these principles to reframe STS 1500 in ways that I hoped would enable students to appreciate better its value and potential to contribute to their professional development. I begin with a brief overview of the course and its major assignments. Then I analyze data in student course evaluations that underscore the difficulty students had in appreciating the course's value. From there, I describe changes I made to the course in the Summer 2019 semester by creating a "real-world" scenario that would involve students in developing new technologies that could help the local university community make progress toward the United Nations Sustainable Development Goals. Finally, I analyze course evaluations that indicate how students responded in the Fall 2019 semester when the teaching team applied the course scenario I had piloted in the summer among ten students to a class of 400 first-year undergraduates.

STS 1500: Course Goals, Themes, and Assignments

STS 1500 (Science, Technology, and Contemporary Issues) is a required first-year course in the core curriculum of the School of Engineering and Applied Sciences that introduces students to social and ethical aspects of engineering design and practice as well as to communication skills required of engineering professionals. The course offers a series of lectures on historical and contemporary case studies in technology that draw attention to their social and/or ethical dimensions, implications, and effects, which students are challenged to consider in the engineering design process. Meanwhile, in weekly labs students work in groups of design teams to execute a series of assignments that task them to apply the principles and lessons covered in the lectures to technical description and design projects. These projects culminate in a group-written provisional patent application that features a new technological design developed collaboratively by the members of each design team.

The course assignments are arranged so that they build on each other by developing skills students will need to execute the patent application successfully. These assignments begin with a design notebook, in which students record fifteen ideas for new technologies by mid-semester. In each entry students identify the problem the technology addresses and write a brief description of its form and function with at least one accompanying figure. The design notebook gives students informal practice in problem definition and technical description while providing a bank of viable ideas from which to develop the patent application.

Early in the semester, students also write a formal technical description. The goal of the project is to give them practice in technical description writing that prepares them for the challenges of writing the patent application. Whereas in the patent application students describe a technology that exists only in their imaginations, in the technical description students are tasked to choose a mundane technological device from their dorm rooms, such as a stapler or mechanical pencil, and describe its form and process of operation with accompanying figures. This assignment allows students to isolate and focus on the descriptive process by concentrating on a device they have at hand that they can see, touch, interact with, and take apart as needed. Later students deploy these skills in the patent application, in which they are tasked to describe an idea that does not yet exist in physical form.

At mid-semester students choose a compelling idea from the design notebook to pitch to their design team. After hearing the various pitches, the members of the team select one of the designs to make the centerpiece of the group's patent application going forward. In the patent application students deploy the skills they have honed in the design notebook and technical description assignments, now oriented around a novel technology of their own design. The project includes all of the conventional elements of a provisional patent application. In addition to a technical description of form and process of operation, the patent application includes a discussion of the design's advantages over prior art, which we have limited to U.S. patents or products. The argument students make hinges on their ability to demonstrate that their idea adds value by providing a better solution to a particular problem than prior art. In order to write the prior art section, students engage in research by using search engines such as Google Patent to find relevant prior art they can discuss and critique. The patent application project culminates in a brief oral presentation in which students describe their technology and its merits over prior art to classmates in their lab.

STS 1500, Fall 2017-Spring 2019: Unrealized Potential

Despite the teaching team's best intentions and efforts, students often produced patents for relatively trivial technologies that addressed problems of mere minor inconvenience, such as a collapsible backpack umbrella or an automated dry-erase board eraser. At the same time, data from student course evaluations[1] indicated that students had difficulty understanding how the lecture topics related to the assignments completed in labs. More importantly, the data also indicated that students failed to appreciate the value of the course and the assignments for their development as professional engineers. The comments below from students on course evaluations illustrate several of these concerns and are typical of the criticisms of the course voiced during the last few years.

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[1] In consultation with a university librarian, I have decided not to include formal citations for the various student course evaluations because they are inaccessible to other researchers and contain information deemed private and confidential. In keeping with the spirit of confidentiality, I have not included any information that might identify a particular course instructor except where I am the sole instructor (i.e. the Summer 2019 course); students' personal information is already anonymous by design in all university course evaluations. IRB approval was sought and obtained for using anonymous qualitative and quantitative data from student course evaluations for this project.

> Fall 2017
>
> Near the end of this semester, I failed to see how what we were learning was relevant. Also, I felt as though this course applied more to people who were interested in entrepreneurship and business rather than engineering. Nothing that I learned in this class applies to what I want to do. I felt like the lecture was more of a history class. It didn't seem to apply to engineering and problem-solving.
>
> Spring 2019
>
> The class and professors seem to have extravagant goals and high hopes for the students, but we were not convinced of the vision that they saw. Many students, including myself, did not put any effort into the course because we were not convinced that it was worthwhile or that any of the content would be useful or pertinent to our lives or our futures. Thus many saw the lecture as a waste of time, thus the low attendance records.

These comments underscore the problem many students have had over the last few years in appreciating the course's value to their professional development. As the comments of the Spring 2019 student attest, students were not motivated to invest in the course because of their perception that its content was not "worthwhile," "useful," or "pertinent" to their academic and professional training. Echoing this sentiment, the Fall 2017 student goes so far as to argue that the course would fit more comfortably in an engineering business or history of technology program than at the core of a required curriculum for all first-year engineering students. As a result, the student concludes, "Nothing that I learned in this class applies to what I want to do." There was, then, a severe disjunction between the course's "extravagant" learning goals and student perceptions of its contribution and value to engineering education and professional practice.

The challenge confronting the teaching team thus became how to increase student perception of the course's relevance and value without necessarily designing an entirely new course curriculum. Although all of us would have been willing to consider major changes to the course's architecture, there were several practical constraints we had to acknowledge that limited the scope of what we could accomplish: the scale of the course (about 400 students each semester), the challenges of collaborative teaching with four to five instructors each semester, the demands of other courses we were each teaching (fourth-year and graduate-level courses), and limits to the amount of time and resources we could devote to making course revisions. Given these constraints, we had to consider carefully and strategically how to reframe the course's existing lectures and assignments in a way that better aligned them with the pedagogical goals of introducing first-year students to social and ethical aspects of engineering practice as well as to the kinds of communication skills often required of engineering professionals.

STS 1500, Summer 2019: Integrating the SDGs

During the Summer semester of 2019 I had the opportunity to teach a version of STS 1500 in the university's Summer Session. The course was targeted especially toward transfer students, who are often eager for opportunities to make progress toward their degrees by taking required courses in the core curriculum over the summer. Ten students enrolled, of whom seven were transfer students and three were first-year student athletes who had pre-season training obligations to fulfill.

To ensure continuity with the experience of the majority of students in the Fall and Spring semesters, I was tasked to retain the course's major assignments and the provisional Patent application as the course's major project. However, I was given liberty to innovate at the thematic level when it came to the course lectures and their relation to the assignments. I knew I needed a mechanism that would help bring thematic unity to the lecture and lab portions of the course and challenge students to develop designs for the patent application that addressed problems of greater significance than mere inconvenience. So I looked to the United Nations Sustainable Development Goals. I realized that the SDGs had the potential to increase students' perception of the course's value to engineering education and practice because they could serve as a compelling means of achieving the strategies for adding value outlined by Ambrose and her colleagues. That is, integrating the SDGs into the course could connect lecture content and lab assignments to "issues that are important to students" and to "real-world event[s]" as well as to the needs of "an actual client in the community" [11].

To realize these objectives, I created an overarching scenario for the course. The scenario asked students to imagine that the United Nations had issued a Request for Proposal (RFP) to engineering undergraduates worldwide inviting them to submit design concepts for new technologies that could help their local universities work toward achieving one or more of the Sustainable Development Goals. The RFP went on to stipulate that the form the United Nations wanted the proposal to take was a provisional patent application along with an accompanying cover letter in which the design team had to make a persuasive argument that its concept design could help members of its local university community achieve at least one specific SDG.

In developing the course scenario, I wanted to strike an appropriate balance between the global and the local. In responding to the RFP, students would be part of a global initiative that putatively involved their counterparts at universities and colleges around the world. Yet by designing with their local university community in mind, students would not be working outside their experience and cultural expertise, nor would they be in danger of adopting a paternalistic attitude toward people in the so-called "developing world" by assuming that they knew best how to design technologies for those living in other nations. Instead, students would have to focus on learning more about the university community they all shared in common in order to discover ways that it could make progress toward achieving the SDGs.

After introducing the course scenario to students, I asked them to familiarize themselves with the seventeen SDGs and to develop a working definition of sustainability based on how the concept is expressed in the various Goals. The aim of this conversation was to help students appreciate the broad notion of sustainability that informs the SDGs. In particular, I wanted students to see that making the world a more sustainable place for all people involves integrating the environmental and the economic with the social and the ethical. In terms of the course goals, then, in order for students to design compelling concepts in response to the UN RFP, it would not be enough for them just to leverage their developing technical expertise; they would have to complement that expertise with a careful consideration of social and ethical aspects of engineering design. By capitalizing on the capacious notion of sustainability that underlies the SDGs, I was able to provide what I hoped would be a more compelling mechanism for integrating the course lectures and labs and for underscoring the relevance of the course, and STS more broadly, to engineering education and practice. Moreover, I hoped that, by designing technologies in response to the UN RFP, students would develop ideas that had the potential to address more substantial and significant problems than those of mere inconvenience. In doing so, they would gain an appreciation for the range of creative and constructive contributions engineers can make toward building sustainable societies.

To give students an example of what it might look like to develop technologies oriented around the UN SDGs, I drew their attention to a device designed by a fifteen-year old high school student from Azerbaijan named Reyhan Jamalova. Jamalova has invented a simple machine that captures rainwater and converts it into electrical energy that can be stored in a battery [14]. Her goal was "to solve the problem of energy deficiency in rainy and low income countries" by designing an inexpensive and accessible source of renewable energy [14]. She calls the device "Rainergy" and envisions that it will help people in her home country and elsewhere contribute toward achieving Sustainable Development Goal 7, Affordable and Clean Energy [14]. Jamalova has gone on to secure a patent for Rainergy and create a company to market her device [15]. In discussing Rainergy with students, I hoped to give them a compelling example of the kind of technology they might develop and articulate in a patent application. I also aimed to inspire them with Jamalova's vision to use engineering to build a more sustainable world, a vision that began by considering the resources and needs of her local community together with the United Nations Sustainable Development Goals.

In addition to reorienting the patent application around the SDGs, I also reframed the other assignments to reflect the UN "Designing for a Sustainable World" RFP. The Design Notebook now included an additional requirement for each entry that students specify how the design concept relates to at least one specific named SDG. This additional parameter to the project ensured that students would be developing ideas in the Notebook that could meet the terms of the UN RFP. I also included an appendix to the technical description that asked students to reflect on the social and/or ethical aspects of the technology they chose to describe. Specifically, I asked students to identify the device's target user(s) as well as any values they thought were embodied in the technology. Then, building on insights from Langdon Winner's seminal essay "Do Artifact's Have Politics" [17], I asked students to reflect on the extent to which any groups of people were either privileged and advantaged or marginalized and overlooked in the technology's design. Finally, after students wrote the patent application, they had to compose a brief cover letter that elaborated how their design concept fulfilled the terms of the UN RFP. This final project required students to make an argument that their designs related to at least one specific SDG and that their technologies could empower specific members of the university community to make progress toward achieving it. I hoped that integrating the UN RFP so thoroughly into each of the assignments would help prevent the SDGs from devolving into a thin and insubstantial veneer loosely placed over the course. Instead, the SDGs would serve as a meaningful connective tissue that bound the varied assignments to each other and the themes elaborated in lecture to the work done in the lab.

Students in the Summer course responded well to the challenge of designing with the SDGs in mind. For example, in past semesters many student groups had devised technologies that could draw on kinetic energy to charge personal devices such as smart phones. One of the teams in the Summer course proposed a design along these lines, but there were important differences that moved the design from one that provided greater personal convenience to one that contributed toward providing clean, renewable energy for the university. It happened that several students in this particular group were on the football team and so regularly engaged in weight lifting regimes at university gyms. Drawing on their experience, they devised a way to store energy generated from the kinetic motion of lifting weights on a bar so that this energy could be used to help power the building itself. Although the concept was similar to those developed by students in previous semesters, the difference was that instead of powering an individual personal device, the stored energy would help power the gym facility, thus providing a way for the university to take steps toward better realizing SDG 7, Affordable and Clean Energy. The team's design, then, illustrated the potential of the SDGs to elevate the significance of designs proposed in the patent application from those that addressed problems of mere inconvenience, such as a low battery on a portable personal device, to those that could provide a source of clean, renewable energy for a larger community.

Student evaluations of the Summer 2019 course were, by comparison with previous Fall and Spring semesters, overwhelmingly positive. One student, for example, commented in a course evaluation that, despite having to take the course to fulfill a requirement, STS 1500 added significant value to his/her experience as a first-year engineering student.

> [The c]ourse was very helpful and insightful especially for a first-year student entering the University and engineering. I took summer session because of Football and the ncaa [*sic*.] requirement. My teacher was excellent and very approachable.

Another student, echoing the sentiment expressed above, draws particular attention to the strength of the lectures, which focused more pointedly on social and ethical aspects of the engineering design process that students would need to consider and leverage to develop a compelling technology for the UN RFP.

> I took this course because it was a requirement, but I love this course because of Professor Laugelli. He was extremely engaging during lecture, and in general the experience of learning with him was one I will not forget.

Although the student's comments focus more explicitly on the instructor's classroom presence and presentation style, it is noteworthy that the overall impression made by the lectures was a positive one. Gone was the sense that the lectures were irrelevant to engineering education or professional practice and unrelated to other aspects of the course such as the assignments.

In addition to qualitative reflections such as those expressed above, the quantitative data in the Summer Session course evaluations also revealed a much stronger perception of the course's value for engineering education and practice. Although Summer Session does not provide overall scores for the course and the instructor, two individual questions are especially relevant for assessing how students viewed the course's contribution and value. One such question asks students to respond to the assertion, "I learned a great deal in this course." Seven students indicated, "(5) Strongly Agree," and the other three answered, "(4) Agree," for a total score of 4.70. The other question then asks students to respond to the statement: "Overall, this was a worthwhile course." Eight of ten students answered "(5) Strongly Agree," while the other two responded, "(4) Agree," for a total score of 4.80. In addition, a further question asks students to consider how well the "course's goals and requirements were defined and adhered to by the instructor." Student responses to this question speak to their sense that all the course materials, from lectures and class discussions, to readings, to videos and films, to activities and assignments, related to the course goals and contributed constructively toward their learning. Nine of ten students responded, "(5) Strongly agree," with the remaining one student replying, "(4) Agree," for a total score of 4.90.

These results indicate that, at least among the ten students enrolled in the Summer course, student perceptions of the course's value had increased markedly over previous semesters. Admittedly, data from only ten students cannot yield definitive conclusions when compared to that from 360-400 students in the Fall and Spring semesters. But the results suggested that reframing the course around the UN SDGs would be an experiment worth trying in the Fall semester to increase students' appreciation of STS perspectives and the course's value to their academic and professional development. There were, however, other variables that could have affected students' overall positive experience in the Summer course. First, instead of being taught by a team of instructors, the Summer course had a single instructor. Second, the scale of the course during the Summer was drastically reduced, which made it not only more manageable logistically but, with a ratio of 10:1, also allowed for greater and more meaningful student-instructor interaction and engagement. That notwithstanding, I was hopeful that implementing changes similar to those I had introduced into the Summer 2019 version of the course would yield comparable and demonstrable positive results in the Fall semester's course.

STS 1500, Fall 2019: Reorientation, Resistance, and Results

In a series of conversations with the two lead instructors of the Fall 2019 course, I persuaded them to adopt the course scenario oriented around the SDGs that I had piloted during the Summer semester. We agreed, however, to make one important modification to the terms of the RFP. In the interest of imbuing the scenario with more realism and local relevance, we changed the identity of the institution issuing the RFP from the United Nations to the Jefferson Trust, which is an arm of the University of Virginia Alumni Association that awards grants to promising research endeavors. This change brought the project even closer to home and gave it greater legitimacy and urgency; it suggested that stakeholders within the university community itself were invested in the SDGs and supporting the development of new technologies that could help achieve them at the local level. We proceeded to introduce students to the course scenario in both the first lecture and lab meetings of the Fall semester.

As the semester progressed students were not only receptive but also resistant to the challenge and constraints of the course scenario. Some of those who resisted the notion of designing with the SDGs in mind pointed to what they saw as the impracticality of the Goals. They argued that without concrete metrics and a framework of accountability the Goals were nothing more than aspirations, which in the end offered little real value. To address these concerns, I directed students to the SDG Indicators website [17] and the *Global Indicator Framework for the Sustainable Development Goals* [18], which articulates accountability structures and metrics for tracking progress toward the Goals. I also provided them with a scholarly essay by Kate Donald and Sally-Anne Way that examines the role that politics played in developing (and softening) accountability measures for the SDGs [7]. I hoped that these resources would acknowledge and validate their concerns while also somewhat ameliorating them at least enough for them to take the course scenario seriously.

Beyond that, I also wanted to address the notion that seemed to underlie their concerns, namely that visionary aspirations, however noble and well-intentioned, have little value without quantifiable results. I directed their attention to Martin Luther King, Jr.'s historic speech, "I Have a Dream." The speech did not offer a series of metrics and accountability frameworks for achieving civil rights for African Americans. Instead, it offered a dream, a vision of what America could be like if its people were to live up to Thomas Jefferson's claim that all men – all people – are created equal. Reflecting on King's speech, I asked students to consider that sometimes what people need as much if not more than metrics and accountability measures is a dream of a compelling new world. This, I argued, is in part what the SDGs offer, a dream of a world in which there is no hunger, no poverty, reduced inequalities, affordable and clean water, responsible consumption and production, and renewed flourishing of life on land and below water. And along with the dream of that new world comes a new approach to engineering oriented around the values embodied in the SDGs. With that in mind, I challenged students to consider how the technologies they would design in class could play a part in realizing the dream that animates the Goals.

Other students resisted the course scenario because they found it too difficult to work under its constraints. Specifically, they claimed that it was too challenging and impractical to design technologies for the university community. These students argued that because students at the University of Virginia are relatively affluent and privileged, the university does not have notable progress to make toward the SDGs. Despite our having told students that the SDGs were universal in scope and not intended only for so-called "developing" nations, these students insisted that the parameters of the scenario were unrealistic and out of touch. Their argument involved a failure of imagination and an unwillingness to research aspects of the university's infrastructure and community that could plausibly make progress toward realizing particular SDGs.

In response to these concerns, I asked students to recall an announcement we had made earlier in the semester at the behest of the Assistant Dean of Undergraduate Education. The announcement concerned a new food pantry that was opening up in the building where the STS 1500 labs meet. The food pantry was intended to address the problem of food insecurity among engineering undergraduates and graduate students. In the announcement from the dean's office, students were informed that at least 11% of college students in the United States experience food insecurity. At the University of Virginia, that would amount to roughly 300 students in the School of Engineering and Applied Sciences. These statistics, together with the creation of the food pantry, suggest that even a relatively affluent university such as the University of Virginia has progress to make toward Goal 2, Zero Hunger, and, implicitly, Goal 1, No Poverty. The challenge, again, was for students to consider how technologies that they could design might play a role in helping the university achieve the SDGs, even Goals that may initially appear not to pertain to them. To do that would require some research and imagination on their parts.

Although some students resisted working with the SDGs, the course evaluations suggest that integrating them into the course themes and assignments generally increased students' perception of the course's value and contribution to engineering education and practice. In response to a question that asked students to identify aspects of the course that most helped their learning, students frequently commended the strength of the curriculum and the course's focus on "real-world" challenges and applications for engineering knowledge

> Very clear and linear curriculum – orientation around real world events made the curriculum easy to follow.
>
> The brad [*sic.*] topics that effect [*sic.*] our current world of technology was [*sic.*] greatly helpful to know. It kept me updated in this fast moving world
>
> I learned about society through taking this course. It forced me to be more aware of the world that I live in.
>
> Assignments/projects had real-world applications

The emphasis in these comments on the course's orientation toward the "real world" points to the role the SDGs played in presenting a realistic and compelling scenario that helped students appreciate how engineering design can help "achieve a better and more sustainable future for all" [2]. Further, the student comments confirm the insights of Ambrose and her colleagues that connecting course lectures and assignments to "issues that are important to students" and "to real-world event[s]" and the needs of "an actual client in the community" can help "increase the value that students place on the goals and activities" of a course [13].

In keeping with these themes, the student comment below expresses a general sentiment regarding the course's value shared by more students than in previous Fall and Spring semesters.

> The activities we had to do in lab were very helpful and worthwhile I felt. The patent writing, Groupwork [*sic.*], design notebook, and technical description were all very interesting and useful assignments to have completed as a first-year engineering student.

The student's remarks highlight the perceived value of the course for engineering education through series of adjectives: "helpful . . . worthwhile . . . interesting . . . useful." These adjectives indicate that the course assignments were both engaging and relevant in that they honed a set of skills that the student thinks are essential to engineering professional development. The student also indicates that there was benefit to working on the course assignments during the first year of study. This observation suggests that the student sees the course as playing a vital role in the school's core required curriculum for first-year engineering undergraduates.

When compared to previous semesters, the quantitative data in the Fall 2019 evaluations also speaks to an overall increase in students' perception of the course's worth. Students who attended the Tuesday lecture (section 001) gave the course an overall rating of 4.06, and those who attended the Thursday lecture (section 002) rated the course overall at 4.01. These numbers represent the first time in many years that the Fall or Spring semester versions of the course have had overall ratings above 4.0. Likewise, when students were asked to assess whether they learned a great deal in the course, those in section 001 responded with 3.64, and those in section 002 with 3.57. When they were asked to rate the extent to which the course was a worthwhile course, students in section 001 answered 3.60, and those in section 002 responded with 3.61. Admittedly, when compared to ratings for other 1000-level courses in the School of Engineering and Applied Sciences in Fall 2019, most of which are not as large as STS 1500, these numbers are still below the mean, which was 4.06 in response to whether students learned a great deal and 4.03 in answer to whether the course was worthwhile overall. Yet the course's overall rating, 4.06 (section 001) and 4.01 (section 002) was much closer to that of other 1000-level courses in the school, which were rated at 4.08.

The significance of the course's Fall 2019 quantitative evaluations comes into greater relief when compared to those of the past few semesters. Table 1 below reports data for each Fall and Spring semester and section of the course from Fall 2017-Fall 2019, with the Summer 2019 semester added at the end. It includes quantitative results for the overall course rating as well as for two questions on the evaluation that assess student perceptions of the course's value.

Table 1. Select STS 1500 Course Evaluation Quantitative Results: 2017-2019

Semester and lecture section	**Instructor(s)**	**Number of student responses**	**Overall Course Rating**	**I learned a great deal in this course**	**Overall, this was a worthwhile course**
Fall 2017 – 001	I-1	179 / 200	3.60	3.56	3.37
Fall 2017 – 002	I-1	163 / 181	3.69	3.58	3.35
Spring 2018 – 001	I-1	177 / 192	3.46	3.31	3.05
Spring 2018 – 002	I-1	172 / 182	3.60	3.44	3.20
Fall 2018 – 001	I-2, I-3	158 / 185	3.88	3.61	3.41
Fall 2018 – 002	I-2, I-3	144 / 183	3.67	3.35	3.29
Spring 2019 – 001	I-2, I-3	148 / 207	3.55	3.14	2.97
Spring 2019 – 002	I-2, I-3	149 / 194	3.59	3.23	3.15
Fall 2019 – 001	I-2, I-3	**152 / 198**	**4.06**	**3.64**	**3.60**
Fall 2019 – 002	I-2, I-3	**131 / 198**	**4.01**	**3.57**	**3.61**
Summer 2019	*I-4*	*10 / 10*	*n/a*[2]	*4.7*	*4.8*

The data in Table 1 underscores the contrast between the Fall 2019 semester and the previous four Fall and Spring semesters. Admittedly, the differences in places between the Fall 2019 semester and the previous Fall and Spring semesters are not dramatic, and the variances among the data are less pronounced than those between the Summer version of the course and

[2] The Summer Session course evaluation does not provide a question about the overall course rating.

previous semesters. That notwithstanding, the results for the Fall 2019 semester are consistently higher than those of past Fall and Spring semesters both for the overall course rating and for the two evaluation questions that assess student perceptions of the course's value. The qualitative comments of students in the Fall 2019 course evaluations discussed above suggest that the "real-world" scenario involving the SDGs likely played a role in students' higher appraisal of the course's overall worth.

I have argued that the data for the Fall and Spring semester shows an increase in students' perceptions of the course's value in the Fall 2019 semester and that the scenario involving the SDGs likely played an important role in this trend. There were, however, at least two other significant variables that may have played a role in the contrast between the data for the Fall 2019 semester and that of previous Fall and Spring semesters of the course. On closer examination, however, it is unlikely that either of those variables accounts for the variances between the earlier semesters and the Fall 2019 semester.

The first major variable was the identity of the lead instructors. In the Fall 2017-Spring 2018 academic year the course was led by a particular instructor (I-1). Then, in the Fall 2018-Spring 2019 year two different instructors co-led the course (I-2 and I-3). So, perhaps the change in instructors accounts for the differences among the data. The average overall course rating for the Fall 2017-Spring 2018 year was 3.58, whereas it increased to 3.67 for the Fall 2018-Spring 2019 academic year. Although the change in instructors may have made a difference between the two academic years, if it were the primary factor in the variances among the data, then the overall course rating for the Fall 2019 semester should be roughly equivalent to that of the Fall 2018-Spring 2019 academic year because the instructors remained the same; the two lead instructors for the Fall 2018-Spring 2019 year (I-2 and I-3) also led the course in the Fall 2019 semester. But the overall course rating of the Fall 2019 semester is distinctly higher than the values for the Fall 2018-Spring 2019 academic year. This suggests that factors other than the identity of the instructor(s) played a role in the higher overall course rating of the Fall 2019 semester.

A second important variable that may have affected the quantitative results in the course evaluations was the presence or absence of a course scenario. In the Fall 2017-Spring 2018 year there was no overarching course scenario that structured the course lectures and assignments. So perhaps the decision to use a course scenario in the Fall 2019 semester, and not the contents or theme of the scenario itself, accounts for the higher overall course rating in the Fall 2019 semester. This, however, was not the first semester in which the course used a scenario. In the Fall 2018-Spring 2019 academic year the course introduced a scenario to provide thematic coherence to the course lectures and activities. The lead instructors created a fictional company, called Orange Inc., and asked students to imagine that they had been recruited by the company and were taking part in a semester of corporate training at Orange University in which they would both learn and shape the values and culture of the company. During the semester students would also be involved in developing design concepts in the patent application that could represent Orange Inc.'s first product to go to market. The qualitative comments in the course evaluations from those semesters indicate that students did not generally receive the Orange Inc. scenario well. The remarks below summarize the sentiment expressed by many students.

> Spring 2019
>
> This class addresses important material, but in a manner that isn't conducive to actually learning. I felt that the fact that we called ourselves "orange university" was counterproductive as it was hard to take seriously. I think this class would be more effective if it was treated like a class and the professors didn't spend so much time trying to make it "fun" by having us pretend to be corporate engineers. I'm here to learn so I realize that not everything is going to be fun, so I feel as though I would get more out of this class if we were just given assignments without gimmicks.

The student's comment indicates that the Orange Inc. scenario came across as contrived or forced, a "gimmick" to make the material more "fun," instead of a constructive tool to motivate student learning. This perception affected how seriously students took the scenario as well as the course and, in this case, led them to undervalue both. So, the presence or absence of a course scenario was likely not a significant variable in the contrasting data between the Fall 2019 semester and previous semesters. The Fall 2019 semester also used a scenario to provide thematic coherence and organization to the course. Yet the overall course rating for the Fall 2019 semester was higher than overall ratings for the year of the Orange Inc. scenario. This suggests that the comparative success of the Fall 2019 semester may have more to do with the "real-world" orientation of its scenario and the capacity of the SDGs to inspire designs for the local university community that addressed more compelling problems of global significance.

Conclusion

I have elaborated how reorienting a required first-year engineering course in STS around the United Nations Sustainable Development Goals increased student perceptions of its value to engineering education and practice. In particular, I described how I reframed the patent application project in terms of a "real-world" course scenario in which students responded to an RFP issued alternatively by the United Nations (Summer 2019 semester) or the Jefferson Trust (Fall 2019 semester) to design new technologies that could help the university community make progress toward the SDGs. The scenario seems to have helped elevate the caliber of the designs by moving them away from addressing problems of mere inconvenience and toward taking on more relevant and significant problems concerning global sustainability that engineering students are likely to care about. I also explained how students in the Fall 2019 semester both welcomed and resisted working with the SDGs and ways that I addressed their concerns. I ended by examining data from student course evaluations, which suggest that reorienting the patent assignment specifically and the course more generally around the SDGs likely played a role in students' increased perception of the course's value and potential to contribute productively to their intellectual and professional development in the first year.

To be sure, the quantitative results from the Fall 2019 semester are not as high as those from the Summer semester, nor were the qualitative comments as consistently positive in Fall 2019 as they were in Summer 2019. Likewise, while the quantitative results in Fall 2019 are higher than in previous Fall and Spring semesters, in most cases they are not dramatically so. At minimum, though, the Fall 2019 data show the potential of an overarching "real-world" scenario framed abound the SDGs to positively impact the value students place on the course and its assignments in a class of 400 students (as opposed to the ten enrolled in the Summer Session course). Further metrics may allow for positing a stronger correlation between the inclusion of the SDGs and the increased value students attributed to the course. One such metric would be the inclusion of a specific question added to future course evaluations that would solicit students' responses to the UN SDG course scenario. The qualitative data gathered from responses to such a question would provide richer insights that may allow for a more nuanced analysis and, perhaps, a stronger conclusion.

In the meantime, it may be worth considering a couple of suggestions voiced in the Fall 2019 course evaluations that shed some light on why the results from that semester were not more significant and how student experience with the course scenario could be enriched going forward. For example, one student began by expressing the familiar frustration that "It was hard to see how the material learned in lecture corresponded to lab." This student went on to recommend "[m]aking them [lecture and lab] more connected," which "would make us engage with the lecture material more." Although students in past semesters have voiced similar concerns, another student offered an intriguing suggestion for how to better integrate the lecture and lab portions of the course. After having acknowledged, "some of the ideas that we explored were interesting," the student explained, "however I do not think that we engaged with them as much as we could have." Continuing, the student recommended that lecture topics be "grouped by UN Sustainable Development Goal" to lend them more appeal, coherence, and correspondence with the assignments done in the labs. This suggestion has merit and is worth piloting in the next iteration of the Summer course and into the Fall. Building on this insight, the lectures could also offer students scholarly methods for embodying values of sustainability in technological design [19], [20] so they can better appreciate how specific engineering choices can advance (or impede) the goal of designing for a sustainable world.

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