Work in Progress: Sustainable Engineering for non-Engineers

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Abstract

Recent shifts in economic and international policy have resulted in environmental sustainability emerging as a rapidly growing education objective. This is especially true in those fields related to STEM and at the post-secondary level. ABET, the accreditation board for engineering and technology programs, identifies sustainability as a realistic design constraint to be implemented into undergraduate engineering curricula, and specifically requires sustainability to be covered in architectural, civil, and environmental engineering programs. However, an understanding of sustainability and how and when decisions related to sustainable practices are made transcends STEM careers. Therefore, education in sustainability should reach all academic majors. For example, at the United States Air Force Academy (USAFA) only 30% of students are enrolled in ABET-accredited engineering programs. However, regardless of undergraduate major, graduates will commission into the US Air Force and be in a position to incorporate sustainability into high-impact decisions within months of graduating. Many go on to serve as high-level decision and policy makers, both during and after their military service. In an effort to extend education in sustainability to all students, a new sustainability course was developed within the Civil and Environmental Engineering department, and will be offered to all students beginning Fall 2019. All degrees awarded at the USAFA are Bachelors of Science (BS) degrees due to the extensive science, engineering and mathematics education students receive. This background allowed the course committee to design a course for non-technical majors which achieves learning objectives through application of technical concepts. All graduates enter into a military career as commissioned officers and are expected to make informed decisions on topics ranging from space operations to routine military installation maintenance and management. To address this wide range of occupational responsibility, the primary learning goal is for the students to be able to integrate and advocate for sustainability principles in plans and decisions affecting the built environment at the conclusion of the course. Course design worked backwards to accomplish this goal beginning with the summative assessment and ending with the individual learning experiences. Using this approach, instructors were able to identify major sustainability concepts critical for achieving the primary learning goal. The Envision framework was used to evaluate and understand the built environment. Some additional concepts included are life cycle assessment, renewable energy, industrial ecology, green building, control systems, transportation and urban design. Students will be assessed at the beginning and end of the course to determine if the course met the primary learning goal.

Introduction

Integration of sustainability in higher education has roots in the 1983 United Nation’s World Commission on the Environment and Development and was furthered by the commission’s Bruntland Report *Our Common Future* in 1987. The report defined sustainable development and outlined three focus categories: economic growth, environmental protection, and social equity
These concepts later appeared as cornerstones of the Triple Bottom Line (TBL), with the goal of introducing and advocating for sustainability in the business sector [2]. In 1992 the United Nations Conference on the Environment and Development in Rio de Janeiro furthered the call to include sustainability in higher education, but a large-scale force to adopt sustainability into higher education did not begin until the UN Decade of Education for Sustainable Development from 2005-2014 [3].

In 2009 a survey of all US institutions found 80% of respondents indicated some level of sustainable topics incorporated in their engineering curricula [4]. Integration of sustainability into undergraduate engineering curriculum can generally be classified into four categories (1) dedicated sustainability courses, (2) integrating concepts into existing courses, (3) linking with a non-engineering department for an interdisciplinary course and (4) courses linked to sustainability, although not explicitly taught (ex: energy and life cycle analysis) [4]. The 2016-2017 Accreditation Board for Engineering and Technology (ABET) Criteria for Accrediting Engineering Programs (2018-2019), Criterion 3- Student Outcomes describes sustainability principles in two outcomes, (c) and (h).

- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

Outcome (c) describes sustainability as a constraint, while outcome (h) indirectly drives towards sustainability through the triple bottom line. Additionally, program specific criteria for Architectural Engineering, Civil Engineering, and Environmental Engineering all require the design portion of their respective curriculums to include sustainability principles [5].

Sustainability is also highly sought after in other disciplines, including the business sector. A corporate drive exists for employees educated in sustainability. Sustainability was called the new frontier of innovation to decrease costs through minimizing inputs and maximize social impacts by the Harvard Business Review in 2009 [6]. Capabilities in sustainability have become a large component in companies and universities, driving business schools to increase education in corporate social responsibility and sustainable management [7].

Sustainable solutions that address our current and future challenges are inherently interdisciplinary. Engineering solutions are implemented in a wider context including social, environmental, and political issues. A survey of employers and universities indicate integration of societal issues with engineering and science are important outcomes for students entering the workforce [8]. While sustainability has been integrated into multiple curriculums across a variety of programs, creating an environment to facilitate deep learning across multiple disciplines poses a variety of challenges. Deep learning is internally motivated and dependent on
a student’s level of engagement with a topic [9]. This means a course seeking to achieve deep learning in sustainability with students from a variety of multiple disciplines must help students develop personal interest in the material [10].

Since the interdisciplinary nature of courses in sustainability can create a wide range of educational outcomes and academic focus, a pilot implementation of an interdisciplinary course on climate solutions was reviewed to understand value to students. The study found on average students rated discussion topics related to their discipline as more relevant than the class average and engineering students rated climate science and renewable energy as more relevant. This indicates student’s backgrounds and interests predispose them to interest in the topic [11]. At the authors’ university the teaching team will not be interdisciplinary, but will draw on concepts from other disciplines to teach an interdisciplinary audience. A major conclusion from the pilot study was to maintain a broad range of topics to make information relevant to all students. With respect to climate change, this allowed 76% of the students understand how their academic discipline’s role in society better [11].

At the United States Air Force Academy (USAFA), the Civil and Environmental Engineering program has taken a broad approach to incorporate sustainability in the curriculum, including construction of a separate course beginning in 2014 [12]. Due to the success of this course and demand from various stakeholders, the department is developing a new course called “Sustainability in the Built Environment” for non-engineers. Course developers intend to offer a moderately technical course that integrates foundational core knowledge to produce graduates with quantifiable competencies related to sustainability. Using published information about sustainability in engineering curricula, developers built a course highlighting emerging issues and core competencies identified by the institution as required background knowledge for all graduates. The built environment was selected as the context to teach sustainability based on the social, economic, and environmental implications of the urban environment. Roughly 50% of the world’s population lives in cities today and by 2030 that number will increase to 60%. Although cities account for only 3% of the earth’s land mass cities consume 60-80% of the world’s total energy and release 75% of the world’s carbon emissions [13].

The primary stakeholder of the USAFA is the Department of Defense (DoD). The DoD outlined four main objectives in the 2016 Strategic Sustainability Performance Plan “(1) continued availability of critical resources, (2) readiness maintained in the face of climate change, (3) waste and pollution minimized, and (4) management and practices built on sustainability and community [14]”. The course is designed to develop baseline competencies in students that prepare them to address these four primary objectives.

All graduates of the USAFA will commission into the US Air Force and serve a minimum of five years. In this position graduates fundamentally are decision makers. Regardless of major, they will be prioritizing, executing and advocating for a variety of projects. Their ability to understand the long term implications of sustainable and resilient infrastructure is critical to
maintaining national defense. Additionally, many graduates will progress to positions with the capability to influence policy and should be prepared to examine the long term impact of the decisions they are making. The course and concepts may translate well to other military commissioning sources.

Initially course developers had to choose between two paths for the course (1) a sustainability course using built environment as the context for learning or (2) a built environment course using sustainability as the context for learning. The development team, consisting of members from the Civil and Environmental Engineering department, thought all graduates should have a clear understanding of the impact of the built environment, but after evaluating the student learning factors, they ultimately decided to design a sustainability course using the built environment to provide context. This course structure allows for other disciplines to learn sustainability principles that can be applied across multiple disciplines and also provides graduates with an appreciation and understanding of the influence of the built environment.

The development team consists of five instructors from the Civil and Environmental Engineering Department with diverse backgrounds. Three of five members are active duty military while the remaining two civilians provide both industry and academic perspective. Each member has different specialties within civil engineering including architecture, construction management, environmental, geotechnical, and structural sub disciplines. Teaching experience ranges from one to 24 years.

Course design followed the approach outlined in “Building a Pathway for Student Learning: A How-To Guide to Course Design.” The pathway uses well-documented principles to shift from an instruction centered paradigm to a learner centered paradigm by starting at the endpoint and working backwards [15]. The process was mostly linear and progressed along the following path; (1) developers identified student learning factors, (2) developed clear learning goals, (3) defined the summative assessment, (4) identified and grouped learning proficiencies, (5) constructed learning experiences, and (6) developed the overall assessment. The course is currently in development. Steps (1)-(4) have been completed at the time of submittal and step (5) is in progress. Results from completed steps are discussed in detail in the following sections.

Student Learning Factors

The knowledge, skills, concepts and beliefs students bring to each course strongly influence their ability to receive and integrate course concepts into their intellectual framework [16]. Course developers assessed the learning factors associated with student’s backgrounds and the USAFA. The high impact factors are outlined below.

Background Learning Factors

At the USAFA, students have defining demographic characteristics that may differ from many other public universities. First, students are proportionally represented from all 50 states with a
small percent from select foreign countries. From this, course developers recognized the course must base examples and conclusions in multiple cultural contexts across all socioeconomic demographics. Second, students enter between the ages of 17 and 23, with 18 as the most common age of admittance. This means many students are still in the relatively early stages of intellectual development where complex, nuanced issues may seem black and white [15]. Sustainability often seeks to optimize impacts with the best result in the grey area, which may make students uncomfortable at this stage of development. In particular, when optimizing a solution with environmental sustainability in mind, the most sustainable solution may not seem sustainable at all. An example of this could be a solution which minimizes carbon dioxide emissions through excessive water usage. Course developers recognize that students may have difficulty recognizing a non-perfect answer as a viable solution to these complicated problems and intend to familiarize students with the complexity, but scaffold assignments to an appropriate undergraduate level.

Institutional Factors

The core curriculum, the collection of courses that all students at the USAFA are required to take, is comprised of an average of 104 of the 146 semester hours required for graduation. The core curriculum is skewed towards technical classes resulting in all students, regardless of major, graduating with a Bachelor’s of Science degree. Prior to their junior year, all students will have taken Calculus I/II, Physics, Chemistry, Introduction to Computer Science, Fundamentals of Statics, and Introduction to Electrical Engineering. These courses build a predictable foundation for course developers, allowing for the inclusion of interdisciplinary topics ranging from transmission and storage of renewable energy to determining and optimizing resource availability, economics, and effectiveness.

The target demographic is students in their junior year. The course is considered part of the core curriculum as an “advanced STEM elective” and expects a minimum of 30% of the student body to enroll. While approximately 30% of the student body major in an ABET accredited engineering program, in order to meet ABET criteria, many of these technical majors’ core electives are constrained to their degree path. For example, Civil Engineering students must take Multivariable Calculus and Differential Equations as their “advanced STEM elective” requirement. Therefore, it is anticipated the majority students who enroll in this course will be from non-engineering majors ranging from English to Military Strategic Studies. Engineering students may elect to enroll in the course to fill an elective credit or in addition to their standard course load. It is important to note the major with the highest projected enrollment in the course is Management due to it being the largest declared major at the USAFA. Approximately 30% of the 2018 graduating class will graduate with a B.S. degree in Management.

Learning Goal

The primary learning goal was developed to be clear and understandable as well as performance based. Course developers used the primary stakeholders of the USAFA to determine the goal.
The first stakeholder is the DoD. All graduating US citizens will commission into the US Military in specialties ranging from space operations to installation management. Graduates will serve a minimum of five years on active duty with varying levels of leadership. Some will be in charge of over 100 people within the first year, while others may only be in charge of small teams after 5 years of service. Many will also oversee multi-million dollar programs. Ultimately, the majority of students enrolled in the course will be able to directly influence the decisions of organizations and individuals within the first five years of graduating. As such, a critical outcome of this course is to develop the students’ ability to assimilate information and make a convincing and well supported sustainable decision that maximizes output while minimizing losses in areas of conflict.

Second, the US Military directly serves every US citizen. Developing decision makers who can advocate for sustainable solutions ultimately maximizes the long term optimization of the triple bottom line, both stateside and abroad, and provides the greatest overall return to the average American citizen. For example, it is well documented that conflict is often kindled by environmental stress. The Syrian uprising was preceded by the most severe drought on record [17]. This destabilized agriculture, leading to increases in unemployment and instability. If the DoD can advocate for missions that seek to mitigate the impact of drought or poor land management, a conflict that is costlier in terms of lives and resources may be minimized or prevented.

Using these two outcomes course developers settled on the primary learning goal of: at the end of the course students will be able to integrate and advocate for sustainability principles in plans and decisions affecting the built environment. The terminology is intentional; integrate implies both a conceptual and technical understanding of sustainability and advocate focuses on empowering students to be confident in their ability to affect positive change.

**Summative Assessment**

Three summative assessments will be used to ascertain if the primary learning goal was met. Students will demonstrate their knowledge on two projects and a final exam. In the first project, students will individually design a net zero home using Energy3D software and a predefined spreadsheet. The project will force students to combine their knowledge of renewable energy with design optimization decisions. The second project will use teams to evaluate the sustainability factors of a military installation. Students will first select and define their metrics. Metrics can span from vulnerability to climate change to the density of housing and walkability of community areas. Students will evaluate their metrics and ultimately use their findings to make a recommendation to improve the installation. Finally, students will be assessed individually on a final exam. The two projects will evaluate process while the final exam will primarily evaluate knowledge in the field.

**Learning Proficiencies**

Learning proficiencies are the capabilities required to reach the overall learning goal. Focusing on the capabilities helped prevent developers from including content that ultimately was not
necessary to achieve the course goal. Over a few weeks course developers independently developed proficiencies with many common threads apparent. The proficiencies were developed using three categories: knowledge, skill and attitude. Knowledge proficiencies addressed the fundamental knowledge required to accomplish the course goal. Skill proficiencies included analytical, thinking, and interdisciplinary capabilities. Attitude proficiencies included the motivation required to be successful in the course, the student’s belief about their capability to be successful and achieve the course goal, and their ability to work with ideas that challenge their current mental models of the world. After developing the learning proficiencies, course developers sorted them into early, middle, and late proficiencies. The timing did not necessarily correspond with the timeline students would learn the material, but focused primarily on the sequence. Table 1 summarizes the learning proficiencies. (K=knowledge, S=skill, A=attitude)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Category</th>
<th>Proficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>K</td>
<td>…know and apply sustainability principles.</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>…explain components of the built environment as they relate to sustainability principles.</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>…describe fundamentals of energy source function and application.</td>
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<tr>
<td></td>
<td>S</td>
<td>…use commonly available sustainability tools to quantify and describe system impact.</td>
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<tr>
<td></td>
<td>A</td>
<td>…recognize their responsibility to act and make sustainable decisions.</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>…explain how all levels of authority influence sustainable policy.</td>
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<tr>
<td>Mid</td>
<td>S</td>
<td>…translate real world examples into mathematical terms.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…use commonly available sustainability tools to quantify and describe system impact.</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>…describe the complexity of real world problems in the context of constraints.</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>…describe requirements and compute expected cost throughout the life cycle of a project, item, or process.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…compute a life cycle analysis.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…calculate metrics for renewable energy and the built environment.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…quantify and interpret values assigned in the triple bottom line.</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>…recognize their ability to optimize the triple bottom line.</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>…seek and articulate sustainable alternatives to an assumed best course of action.</td>
</tr>
<tr>
<td>Late</td>
<td>S</td>
<td>…compare design decisions and determine sustainability impact.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…determine and optimize resource availability, economics, and effectiveness.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…optimize various courses of action, given constraints.</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>…recognize their capability to act and make sustainable decisions.</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>…use commonly available sustainability tools to quantify and describe system impact.</td>
</tr>
</tbody>
</table>

Table 1: Learning Proficiencies
Learning Experiences

Learning experiences are being constructed using the proficiencies identified above and are currently incomplete. To meet the goal of using the built environment as the context for sustainability course developers are using many concepts from the Envision infrastructure rating system to evaluate solutions and develop context for in class examples. The Envision rating system uses 60 criteria to evaluate the sustainability of infrastructure projects. These 60 sustainability criteria span the lifecycle of the project and include topics ranging from community involvement in the planning phases to the impact of the project on climate change. Overall, the system incorporates the triple bottom line into all phases of a project [18]. Many of the specific criteria may help students understand the specifics of sustainability.

Sustainability is an interdisciplinary topic, and course developers took an intersectional approach to topics, in particular the realm of the overlap between a student’s aptitude and their attitude towards a topic. The fundamental interests of other academic major’s curriculums were considered in building assignments and approaches to material. On group assignments there will be opportunities for students to contribute value from their academic background and interests. For example, a project discussed above asks students to design a net zero home using Energy-3D [19]. In addition to the design, students will be asked to determine the monetary break-even point. Course developers envision a student motivated to work in design will contribute the home construction and students interested in business can provide the economic analysis. Course designers hope this sparks interest and bridges between academic majors.

Overall Assessment

Course Assessment

The course outcomes will be assessed in two methods, and course developers are investigating a third. The first is driven by the USAFA’s Engineering Method’s Outcome Team. Within the framework developed by the Outcome team for the institution as a whole, this particular course is designed to answer two of six outcome proficiencies. The first of the expected proficiencies is that students will exit the course with fundamental domain knowledge about principles governing defense of infrastructure. The second is that students will be evaluated on their decision making skills and ability to generate design solutions in constrained environments. The proficiencies will be evaluated using a combination of final exam questions and an end of course project. The project directs students to evaluate a military installation across five categories and generate recommendations for improved sustainability and resiliency.

The second method for assessing course outcomes will be the use of the Sustainability Literacy Test (www.sulitest.org) to assess the progression of students’ understanding of basic, and often misunderstood, concepts related to sustainability. Students would take a survey prior to beginning the course and upon completion of the course. The test is designed to detect common misunderstandings and gaps in sustainability knowledge, therefore minor adjustments could be
made to the course to meet the needs of students. Results will be compared to similar demographics in the US as well as internationally, providing assessors with valuable information about students’ competencies. After the initial offering of the course, course developers plan to use average deficient scores to identify areas for improvement in the course.

The third method for assessing course outcomes that is still being explored by the course development team is the use of an initial survey that all freshman at the USAFA would take. The survey asks a variety of questions used to evaluate progress over their undergraduate education. Course developers could have a number of sustainability focused questions included, but, as this course is not mandatory for all students, there are concerns about statistical noise in any data comparing average results from freshman year to after the course is completed.

Student Assessment

While the primary student will be a non-technical major, the course will have technical majors who elect to take the course to fill semester hour requirements. All students who enter the USAFA are expected to have aptitude to succeed in any major. The decision to declare a non-technical major speaks to the attitude of students, not the aptitude. Course developers believe the attitude will drive the student outcomes, given many students have a baseline aptitude for all subjects. While the core curriculum is strong and lends itself towards students being more comfortable with engineering problems, course developers believe the topics will translate to other universities, especially the interdisciplinary focus of the course which strives to be inclusive of a wide variety of personal and academic interests. The non-technical majors may feel more comfortable with the technical material based on previous exposure, but if attitude is the driving factor, most students should be successful with a basic understanding of math, physics, and social sciences. The course developers are exploring options to compare the outcome of technical majors to non-technical majors enrolled in the course.

Conclusions and Feedback Requested

Course developers are successfully using the approach defined in “Building a Pathway for Student Learning: A How-To Guide to Course Design” and are optimistic the course will meet the learning goal. No results are currently available. A pilot version of the course will be offered Fall 2018 and the full course will be open to full enrollment Spring 2019.

Course developers are seeking feedback on evaluation tools, highlights from other curriculum development, and ideas for improvement. Results will be shared after implementation.
References


