2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33977

Assessing the Sustainability Components of Engineering Capstone Projects

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Leslie Brunell, PhD, PE is a Teaching Professor at Stevens Institute of Technology. She coordinates both the civil and multidisciplinary engineering senior design projects. These projects are the culmination of the undergraduate engineering experience. Students design an innovative solution to a complex problem. She has recruited professional sponsors who mentor the civil engineering design projects. The projects expose the civil engineering students to real world design problems. The students gain first hand experience communicating professionally, developing schedules, meeting deadlines and preparing professional quality reports and presentations. Prof. Brunell is the director of the Water Resouces graduate program. She also teaches Fluid Mechanics, Surveying and Water Resources. Professor Brunell also advises Sustainability Management Master's students as they complete their capstone design.

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Alex Dubro is a May 2020 graduate of the Master's program of Sustainability Management at the Stevens Institute of Technology (SIT). While at SIT, he co-founded the Stevens Sustainability Coalition (SSC), which establishes on- and off-campus partnerships between Subject Matter Experts (SMEs) to deliver outcomes that integrate sustainability in their results. In addition, the SSC builds community by holding social events, such as potlucks, incubation expos, and workshops. Collaborating with a peer, he assisted the school in achieving AASHE Gold by leveraging the SSC's network to draft and disburse the Sustainability Literacy Assessment (SLA). He aspires to give instructors and students a deeper meaning of sustainable development: by using the principles of sustainability management, e.g. lifecycle assessment (LCA), the 3-P paradigm.

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Assessing the Sustainability Components of Undergraduate Engineering Capstone Projects

Abstract

Undergraduate engineering capstone projects are frequently structured and organized to meet standards, such as the ASCE BOK, PMBOK, Agile, IEEE, and ABET. Just as professional engineers (PEs) have clear guidelines and instructions for delivering outcomes to clients, capstone projects consider the client's needs and meet rigorous academic requirements. With the increased need to integrate or address sustainability concerns in all areas of study, undergraduate engineering capstone projects should have universal standards to incorporate sustainability. Regardless of the type of project, clear, streamlined standards would help assess the sustainability components, even if the project directly addresses sustainability, e.g. green infrastructure, solar energy. To fulfill the capstone requirement for a Masters of Science in a Sustainability Management (SM) program at Stevens Institute of Technology, the Co-author designed the Sustainability Implications Scorecard (SIS) while working with several Senior Design capstone coordinators. The student additionally conducted field research, interviews, and benchmarking against the UN SDGs, Envision, and ABET.

The SIS is a flexible, adaptive, and project-focused rubric that simultaneously guides and evaluates how successfully an engineering design or project team integrates sustainability components. In particular, it evaluates on the basis of key learning outcomes that measure research, comprehension, leadership, professionalism, and communication skills, both oral and written. The rubric is composed of the following: (1) Research & Sustainability Analysis, (2) Project Development, (3) Teamwork & Leadership, and (4) Deliverables. Each section of the rubric addresses a necessary area:

1. Research & Sustainability Analysis – Students research and analyze sustainability's meaningfulness to the project and show how to address stakeholders' needs and project trade-offs.
2. Project Development – Students complete the project within schedule while meeting pre-set and targeted sustainability goals.
3. Teamwork & Leadership – Students collaborate and self-reflect on strengths and weaknesses as leaders and teammates while understanding how sustainability influences decision-making.
4. Deliverables (Written & Oral Reports) – Students write about and present their research, designs, and sustainability analysis (e.g. meaningfully, concisely, scientifically).

Although the SIS was originally developed for the SM capstone project requirement, it was applied, modified and updated to the Sustainability Components Assessment (SCA) to focus on sustainability research and analysis and communication of sustainability findings. The SCA was recently used as a case study within a civil engineering Senior Design capstone course at Stevens Institute of Technology in order to find areas of strength as well as appropriate revisions, and to answer multiple research questions. This research has led to a more robust, comprehensive, and complete assessment tool, now developed as a web-based application, that will assist professors in higher education who are required to incorporate sustainability into their capstone courses in addition to encouraging SCA Online use throughout engineering curriculums.

Introduction

Engineering undergraduate students in ABET-accredited universities are required to complete capstone projects that evaluate how well they apply their knowledge and skills to design projects. These projects do not have to be academic; in fact, real-world design problems are encouraged. Professional mentors often work with students to solve design problems that parallel work they are doing or explore unique approaches to existing designs. Requiring an end-of-college project, rather than a thesis, often boils down to a single, overarching objective: to cultivate entry-level engineers for real-world challenges, as leaders and teammates, while holding students to rigorous academic requirements. Currently, there are no universal standards in place that evaluate how effectively students integrate sustainability analysis into their designs; those that exist are not comprehensive, often focused on one particular component [1].

In addition, there is an increased need to integrate or address sustainability concerns in all areas of undergraduate-level study. Engineers, whether working as independent contractors or within larger firms, are no longer evaluated on completing the project's scope but on how they use sustainability to comply with the law, decrease costs, increase brand equity, and attract investors. Students must be prepared to deliver on outcomes for public and private organizations, which entail a variety of skills: strategic benchmarking, research, project scoping and scheduling, risk management, role assignment and task delegation, collaboration, decision-making, conflict management, and oral and written communication. In other words, society needs engineers who are not just professional and prepared for work, but experienced citizens of the world, ready to overcome the challenges of the 21st century.

Enhancing student knowledge of sustainability within the capstone design course prepares engineering graduates for the challenges they will face as they move into their professional careers while also meeting the ABET criteria, namely 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" [2]. Adding sustainability tasks into their proposed designs encourages the students to think about the larger impact of their projects. Consideration of sustainability within the undergraduate capstone design is linked to professional ethics for all civil engineers, as noted in the BOK3: "striving to comply with the principles of sustainable development in the performance of their professional duties" [3]. Using both the UN SDGs and Envision is a realistic way to bridge the gap between the undergraduate design experience and the professional expectations students will be obligated to consider in their future careers [4].

Rubrics are frequently used in academia for assessing student performance and evaluating program outcomes. Rubrics are advantageous because, in addition to allowing for assessing student work, they can be used to directly assess student performance while meeting the criteria established by both ABET and ASCE. When focusing on sustainability, the literature is rich with examples of rubrics that focus on environmental, social and economic goals for sustainable development [6]. Many of these rubrics utilize existing rating systems such as LEEDS, Staunch, Envision and others to help students think about sustainability [5], [6].

Background: Sustainability Implications Scorecard (SIS)

The sustainability rubric herein began as a capstone project by the Co-author who was fulfilling the requirements for a Masters of Science in Sustainability Management (SM) at Stevens Institute of Technology. The rubric was the focus of the core capstone design project and was completed in 3 months, beginning in March 2020 and finishing in May 2020. Interviews with professors, undergraduate students, and staff at university sustainability offices were conducted. Additionally, field research was done by reviewing websites covering undergraduate student capstone projects and attending the design day expo of undergraduate students' 2020 capstone projects.

The SM capstone project produced the Sustainability Implications Scorecard (SIS), which was designed to evaluate how effectively undergraduate engineering students incorporate sustainability components into Senior Design projects and prepare them for understanding how important sustainability will be in their careers, as well as promote a global awareness of their designs. Just as Senior Design is the culmination of a student's undergraduate experience, the rubric measures mastery of their knowledge of sustainability and its significance beyond the classroom, particularly cultural, economic, environmental, political, and social implications.

Sustainability components measured within the rubric assess skills including research, comprehension, leadership, professionalism, and oral and writing skills. The rubric was grouped into 4 sections: (1) Research & Sustainability Analysis, (2) Project Development, (3) Teamwork & Leadership, and (4) Deliverable (Written & Oral Reports), Table 1. Each section connected to a given skill by using key learning outcomes in the form of sub-sections, making the rubric comprehensive and thorough. Each sub-section could be given a score on an interval of 0-4, then the scores were added and divided by the total possible points (60) to determine the grade. A white paper accompanied the rubric to guide instructors in completing the evaluations, as well as explaining the rubric's purpose.

Table 1: 4 Sections & Corresponding Sub-sections of SIS

Section	Focus	Sub-sections
Research & Sustainability Analysis	Doing college-level research and analysis that show a deep understanding of sustainability	1. UN SDGs 2. Benchmarking 3. Methodology 4. Sustainability Understanding
Project Development	Completing projects within expected time frames, which is expected of Project Management Professionals (PMPs)	1. Project Schedule 2. Milestones
Teamwork & Leadership	Collaboration and self-reflection on strengths and weaknesses as leaders while understanding the extent to which professionals influence decision-making	1. Collaboration (Team Effectiveness) 2. Leadership Effectiveness (Self-reflection) 3. Leadership & Decision-making
Deliverable (Written & Oral Reports)	Effective oral and written presentation of research and sustainability analysis (e.g. meaningfully, succinctly, scientifically)	1. Thoroughness/Comprehensiveness 2. Organization & Structure 3. Visual Appeal 4. Clarity 5. Meaningfulness/Significance

The section Teamwork & Leadership allows the instructor to directly assess leadership and collaboration within each team. Collaboration, as a sub-section, measures how effectively students work together to deliver on the project's scope of work, displayed by several key performance indicators (KPIs). As with every sub-section, instructors must ask whether students accomplished what is asked of them, as listed by several essential questions. For Collaboration, those essentials questions are:

1. Is there a clear, concise mission statement that covers the 5 W's?
2. Is there a division of labor (DoL) that is clearly explained and assigns responsibilities based on team member's strengths and weaknesses?
3. Do students work under a shared leadership model and understand its benefits/challenges?

Grading for each sub-section is sequential, building upon each essential question. A grade of 0 for Collaboration indicates that students accomplished none of the outcomes required by the essential questions, and as each essential question is answered, the instructor provides the student with a score, arguing that "Students have a clear, concise mission statement, with strategic DoL, goals/mission, and collaborated using shared leadership." The ubiquity of the grading style makes for streamlined, universal coding for grading regardless of the engineering or science discipline of the student team.

Phase 1: From SIS to Research Study on Sustainable Engineering Design

Before the Authors began the research study, the SIS was distributed to senior capstone coordinators within Stevens Institute of Technology as a simulation. 4 professors completed the rubric for independent design projects: 1 in mechanical engineering, 2 in ocean engineering, and 1 in civil engineering. The results were low, with the maximum and minimum scores being 68% and 47%, respectively. The mean and median scores were 60% and 63%, respectively. Professors' scores throughout the various sub-sections of the SIS were low as well, and this was a recurring pattern. For example, one professor's scores for Sustainability Analysis, composed of UN SDGs, Benchmarking, Methodology, and Sustainability Understanding, were 1, 0, 0, and 1. Another's were 1, 3, 3, and 2.

Given that mean and median Senior Design final grades are rarely below 80%, the results were surprisingly low. Because the SIS was used as a grading instrument, it served as an incentive to ensure that students incorporate sustainability into their engineering design. Additionally, it motivates instructors to educate students on the importance of sustainability within any engineering design. This was the primary motivation to conduct the research: to validate the SIS for use by instructors.

The civil engineering senior capstone course begins with students selecting their infrastructure design projects at the beginning of the fall semester. Once the design teams were formed, the researchers distributed an assignment focused exclusively on the United Nations Sustainable Development Goals (UN SDGs) and each project's ability to achieve two goals. Students were asked to write briefly on what the SDGs are, then choose one direct and one indirect UN SDG to incorporate into their proposed engineering design project.[1] Sustainability was first introduced within the context of the UN SDGs. These goals were presented as a way of incorporating sustainability into the design projects. Each student had to identify at least one direct and one indirect goal for their design and then the team worked together to identify the best direct and indirect goals to focus on as they developed their proposed designs. The UN SDGs helped the students gain an understanding of the impact engineering solutions have on globally recognized economic, environmental and societal contexts [7].

The research began in the fall 2020 semester as a series of efforts to measure, report, and publicize the SIS' reliability and validity. Using a civil engineering capstone course as its case study, the researchers analyzed grades relating to sustainability and observed how students' communication changed over the course of the semester.

The students had to consider the impact of applying sustainability's core themes: people, planet, prosperity, peace, and partnerships. Students needed to include details of their proposed design, as well as statistics and facts provided by the UN. Out of a class of 43 students, 41 completed the

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[1] A direct goal is one in which the engineering proposed design directly achieves its impacts. For instance, SDG 6 (Clean Water & Sanitation) asks students to show how their proposed design directly achieves such. At the same time, an indirect goal is one in which that same proposed design indirectly achieves those impacts. For instance, SDG 16 (Peace, Justice, & Strong Institutions) asks students to show how their proposed design will let the direct goal be achieved.

assignment. These grades were compared to the student teams' Final Written Reports, Table 2. While not sharply different than the scores of that assignment, there was considerable spread:

Table 2: Comparison of Student Grades

Assignment	Mean	Median	Max	Min	Standard Deviation
UN SDG Assignment	84	84	96	68	8
Final Written Report	89	90	96	82	5

That spread becomes more obvious when comparing histograms. The first set of histograms, figure 1, show the students' grades on both assignments while the second, figure 2, shows those scores standardized, otherwise known as Z-score normalized.

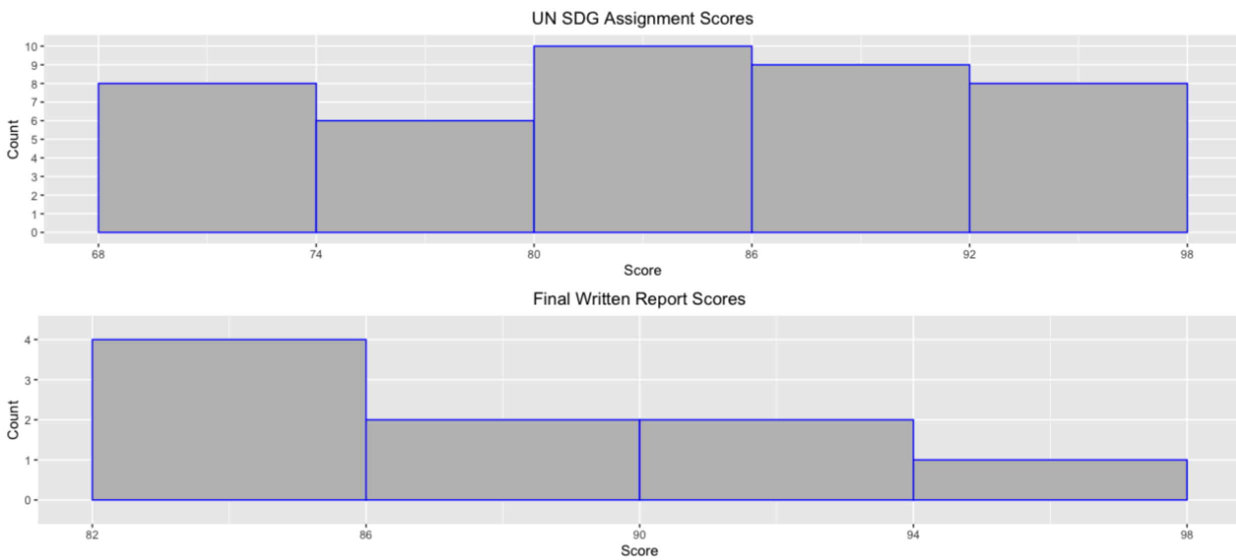

Figure 1: Student Grades

Figure 1's histograms show the counts of each score, with the binwidth and numbers of bins appropriate to the counts. The spread for the UN SDG Assignment was much larger than the Final Written Report, with a range of 28, minimum of 68, and maximum of 96 relative to a range of 14, minimum of 82 and maximum of 96, respectively. This spread becomes considerable when looking at figure 2's histograms:

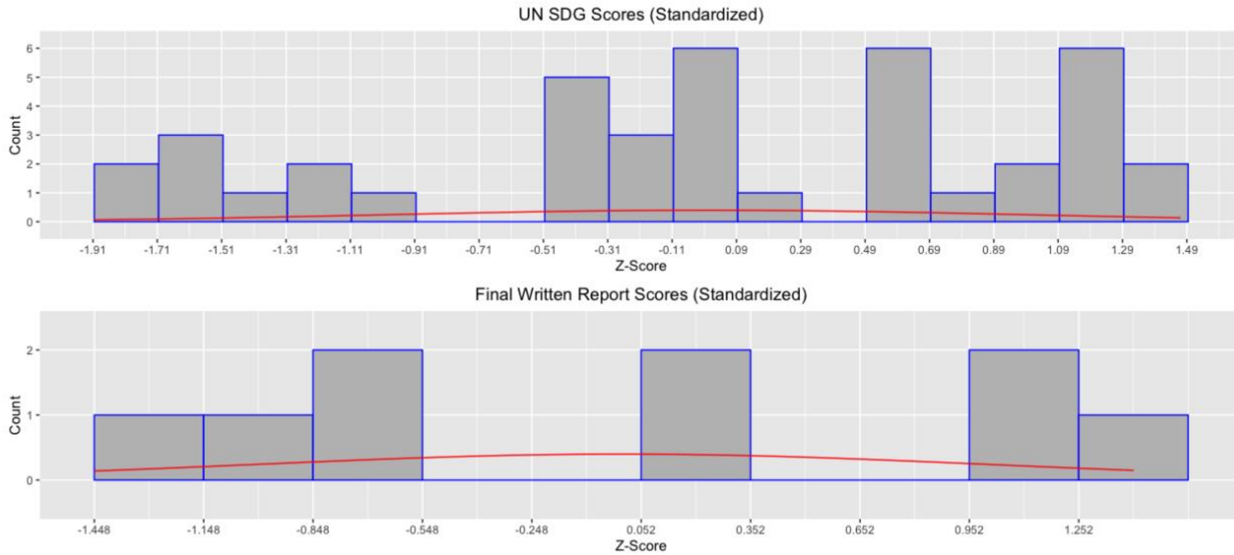

Figure 2: Student Grades, Standardized

When considering the standardized scores, the UN SDG Assignment's Z-scores range from -2.0 to 1.6, with a relatively equal count of each Z-score. As a result, the Z-scores result in a very flat, if not horizontal, standard normal curve. On the other hand, the Final Reports scores' Z-scores range from -1.6 to 1.4, with a slightly tighter curve. That leads to the following conclusion: While students' grades for both assignments are widely spread, the spread for the final written reports is much less than for the UN SDG assignment. In other words, more attention needs to be given to sustainability-related assignments than for typical engineering assignments so that the spread of the first graph can be closed. The SIS is, indeed, necessary, but an essential question remains: Is the SIS doing what it intends to do? Will it close the gap seen in the UN SDG Assignment scores?

To test this further, the SIS was distributed once more to 16 professors in December 2020, of which 2 completed it. Both participants were in the mechanical engineering field; however, their results were wildly different: 95% and 50%. One participant provided extensive feedback:

> I found some parts of this difficult to fill in as there really isn't any emphasis placed on sustainability from the grading perspective as I have seen it…I have never been asked to assess any of our projects related to sustainability. It was also unclear in some sections whether the rubric refers to the various questions in the context of sustainability or not. If it is all meant to be in the context of sustainability, some of my scores would have been lower.
>
> I would also add that this team is doing very well - just sustainability is not a consideration in many of the ME projects…what matters to the students is grades and I have not seen any important grading based on sustainability in the past.

Feedback from the December 2020 distribution illuminated the differences in scores between the UN SDG Assignment and Final Written Report and highlighted the SIS' weaknesses. First, the

SIS covered too much ground. That it covered too many sustainability components is the reason that student groups were receiving grades as low as 47% in the first distribution and 50% in the second distribution while still earning a wider spread of scores on assignments focused primarily on sustainability. In addition, the SIS purported to evaluate student groups on sustainability analysis; however, it didn't give instructors the means to do so. Professors were not "asked to assess" projects with regards to sustainability. Instructions that stated "Please complete an evaluation on Sustainability Research & Analysis" were unclear. Those fields that did not have to do with sustainability left professors confused. Were professors being asked to evaluate project management in general fields exclusively or "in the context of sustainability?"

As this professor states, "sustainability is not a consideration in many of the ME [mechanical engineering] projects," which is what led to the 50% grade. Instead, "what matters to the students is grades"—and those grades are based on established learning outcomes. Overall, the rubric doesn't evaluate students thoroughly enough on sustainability analysis for engineering design projects, not to mention that it needs to be easy for professors to evaluate sustainability.

Reviewing the rubric for the UN SDG assignment, there should be more focus on sustainability research and analysis. This includes financial materiality, fiduciary duty, knowledge of sustainability, and historical awareness. Even criteria that are not directly sustainability-related, e.g. incorporation of engineering concepts, are not accounted for in the existing SIS. Some sub-sections of "Sustainability Analysis & Research" are inappropriate for engineering students. These included criteria that engineers should not be measured on, e.g. stakeholder engagement and materiality assessment. In addition, benchmarking should focus on a fixed set of criteria, like the UN SDGs or other standards used to evaluate sustainability such as Envision, LEEDS, and the like.

The SIS was a good proof of concept (POC) at its conception. However, it was an "in-between" grading instrument: It did too little when evaluating engineering projects on sustainability incorporation while trying too hard to compress many criteria for evaluating a project's success. As a result, it loses sight of its primary goal: evaluating students on incorporating sustainability research and results into their engineering designs. Therefore, a new rubric needed to be designed. With the conclusions drawn from analyzing grades and distributing the SIS, the Sustainability Components Assessment (SCA) was developed.

Phase 2: Drafting a New Proof of Concept on Sustainable Design

The SIS was redrafted in January 2021 with a focus on guiding instructors on sustainability components that measured skills covering research, engineering design, creativity, awareness and sensitivity, and oral and writing skills (of sustainability research). The rubric followed the same format and structure as the original SIS and was grouped into the following 4 sections: (1) Sustainability Awareness, (2) Design Incorporation, (3) Innovative Thinking, and (4) Effective Delivery, Table 3. The scoring was slightly different with the total possible points reduced to 44. A white paper accompanied the rubric to guide instructors in completing the evaluations, as well as explaining the rubric's purpose, which is especially important considering the updated version.

Table 3: 4 Sections & Corresponding Sub-sections of SCA

Section	Focus	Sub-sections
Sustainability Awareness	Doing college-level research and analysis that show a deep understanding of what sustainability means	1. Knowledge of Sustainability 2. Historical Awareness 3. Global Sensitivity
Design Incorporation	Incorporation of sustainability analysis into the engineering design and using relevant engineering concepts for the analysis	1. Feasibility of Proposed Design 2. Relevance to Engineering Design
Innovative Thinking	Analytical and creative incorporation of sustainability analysis into the engineering designs with attention to financial and social impacts	1. Analytical Thinking 2. Methodology 3. Fiduciary Duty
Effective Delivery	Effective oral and written presentation of the sustainability analysis (e.g. meaningfully, succinctly, scientifically)	1. Thoroughness & Comprehensiveness 2. Organization & Structure 3. Clarity & Meaningfulness

Phase 3: Results of Updated SIS

The updated SIS, now termed the Sustainability Components Assessment (SCA), was distributed to the mentors of each student team's project. Of the 10 teams, 9 mentors completed the SCA. One team whose scores were previously excluded were again excluded because their scores serve as an unrepresentative outlier and would skew the results unfairly. Therefore, the results presented are based on the scores of 8 design projects. Several of the teams had multiple mentors with more than 1 person completing the rubric, so when calculating sample statistics, their scores were averaged with equal weighting to each mentor.

Table 4: Statistics of Jan. 2021 SCA Evaluations

	Final	Sustainability Awareness	Design Incorporation	Innovative Thinking	Effective Delivery
Mean	0.75	0.69	0.85	0.73	0.75
Median	0.72	0.73	0.92	0.71	0.75
Max	0.95	0.90	1.00	0.94	1.00
Min	0.45	0.42	0.50	0.50	0.25
Standard Deviation	0.16	0.16	0.19	0.16	0.24

Scores for the SCA were higher than the first distribution of the SIS, with the mean and median being 15 and 9 points higher, respectively, Table 4. (The mean and median scores of the SIS were 60% and 63%.) Additionally, the maximum score was higher by 27 points, though the minimum scores were approximately the same.

Students did well in sections more geared toward engineering than creativity, communication, and an understanding of sustainability. Design Incorporation's mean and median scores were 85% and 92%, respectively, and the maximum score was 100%. On the other hand, Sustainability Awareness, which challenges students to think more deeply about the development of the UN SDGs and their general relevance, as well as a sensitivity toward the meaning of sustainability in different cultures, was markedly lower, with mean, median, and maximum scores at 69%, 73%, and 90%. Students did not fare that well on Innovative Thinking and Effective Delivery, either: Mean and median scores remained at or below 75%.

To corroborate findings, several independent two-sample t-tests were conducted for Design Incorporation relative to the three other categories. In other words, are Design Incorporation grades higher than the others? The results found that Design Incorporation scored significantly greater than Sustainability Awareness and Innovative Thinking ($t(7) = 1.86$, $p < 0.05$; $t(7) = 2.68$, $p < 0.05$). Design Incorporation, however, was not significantly greater than Effective Delivery ($t(7) = 1.39$, $p > 0.05$).

All of this points to a key conclusion: Students know how to do sustainability, as practicing engineers, but writing about its meaning, reflecting on what it means to peoples of other regions, and doing sustainability analysis in ways foreign to them may still be a challenge.

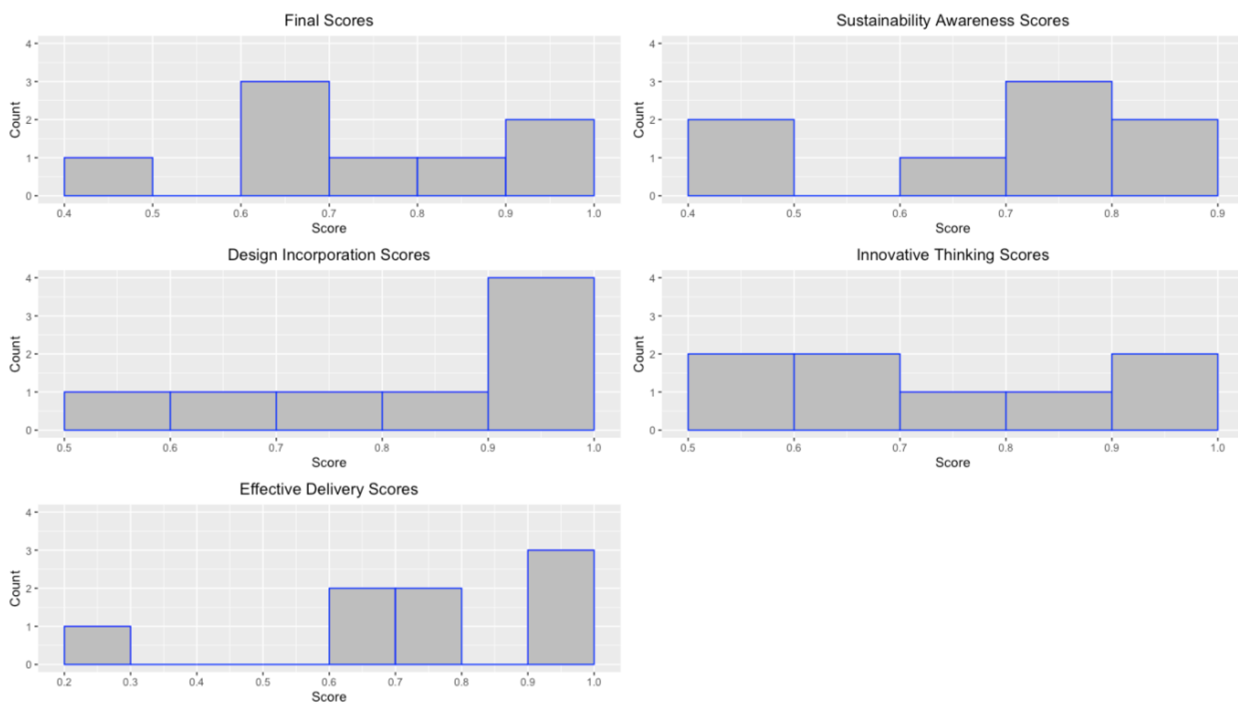

Figure 3: Jan. 2021 SCA Evaluations

Figure 3 emphasizes this finding by showing the distribution of scores. Some student groups did very well, earning scores greater than 90% as a final score, though most were in the 70%'s. At the same time, Sustainability Awareness and Innovative Thinking scores were quite spread out, and Effective Delivery scores less so. Design Incorporation was mostly above the 80%'s, though a few teams were below. The normalized scores, Figure 4, points out how skewed scores were, with Final, Sustainability Awareness, Design Incorporation, and Effective Delivery scores hovering close to the means, though the last three much less so. Innovative Thinking, while carrying a mean and median score lower than Design Incorporation, showed a spread considerably similar to the Final Scores, indicating that its scores may have been dragged down due to a few outliers. Effective Delivery and Sustainability Awareness, however, were much less spread, indicating that their mean and median scores reflected the true values of the sample, similar to the Design Incorporation scores. The standardized scores corroborate aforementioned findings, showing where students' scores were mostly spread:

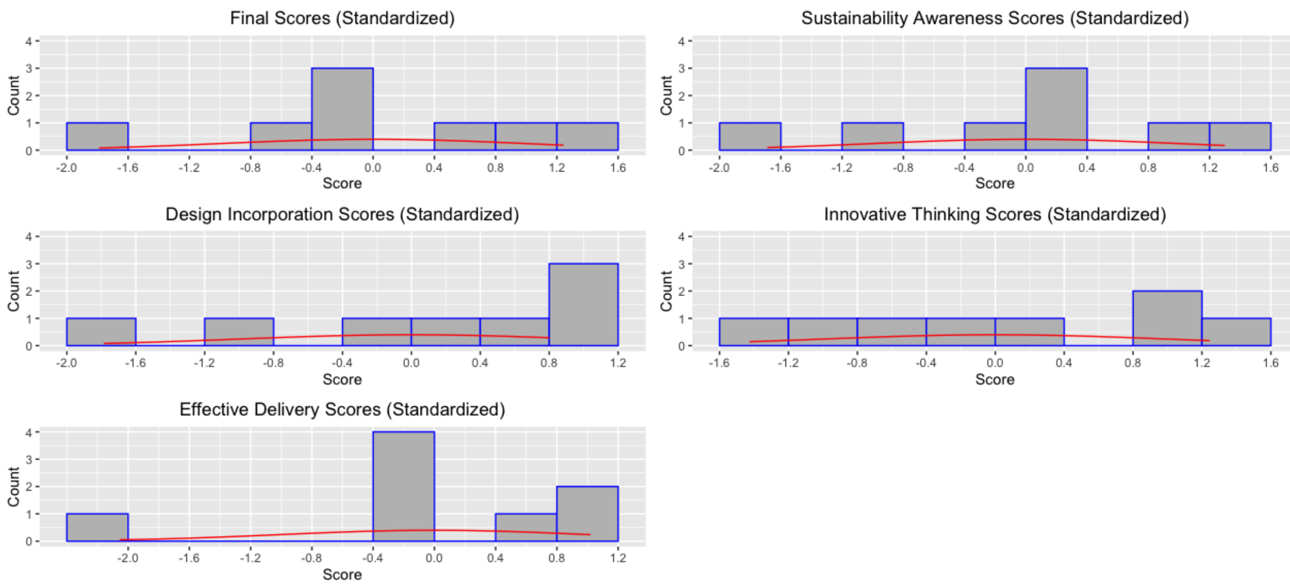

Figure 4: Jan. 2021 SCA Evaluations, Standardized

To measure if there were any meaningful differences between student grades and the SCA evaluations, several statistical techniques were used. Because normality was not met for the UN SDG assignment dataset, a trimmed means t-test was conducted for the UN SDG assignment scores and SCA evaluations. A Welch's unpaired t-test was conducted for the final written reports and SCA evaluations. The former revealed no statistical significance between student UN SDG assignment grades and the SCA evaluations ($t(6) = 1.61$, $p > 0.05$). On the other hand, the latter revealed statistical significance between final written report grades and SCA evaluations ($t(8) = 2.41$, $p < 0.05$).

Usually, statistical significance is desired in two-sample t-tests, as is the case for pre- and post-treatment groups. However, that significance in the difference in means between the UN SDG assignment scores and the SCA evaluations was not met does the opposite; it highlights that lower grades on sustainability assignments is related to mentors' grading of student skills. In other words, that there is no difference between scores indicates that this was not a random coincidence. On the other hand, the significance in the difference in means between the final written report scores and SCA evaluations highlights that there is no exact statistical relationship between sustainability analysis by mentors and capstone coursework. In other words, this also indicates that the difference between these scores was not a random coincidence. Because sustainability is not a core component of student grading, a relationship is not expected. Indeed, another trimmed means t-test highlights exactly this: When comparing the sustainability analysis criterion from the final written reports, the results are similar to those of the UN SDG assignment scores and the SCA evaluations ($t(7) = 1.24$, $p > 0.05$).

To further validate the relationship between the final written report scores and SCA evaluations, the samples were paired and plotted. The team that did not receive an SCA evaluation was treated as a null value; for those teams with multiple mentors, the grade was averaged, with equal weighting between the mentors. Figure 5 shows that relationship ($r(6) = -0.002$, $p = 0.996$).

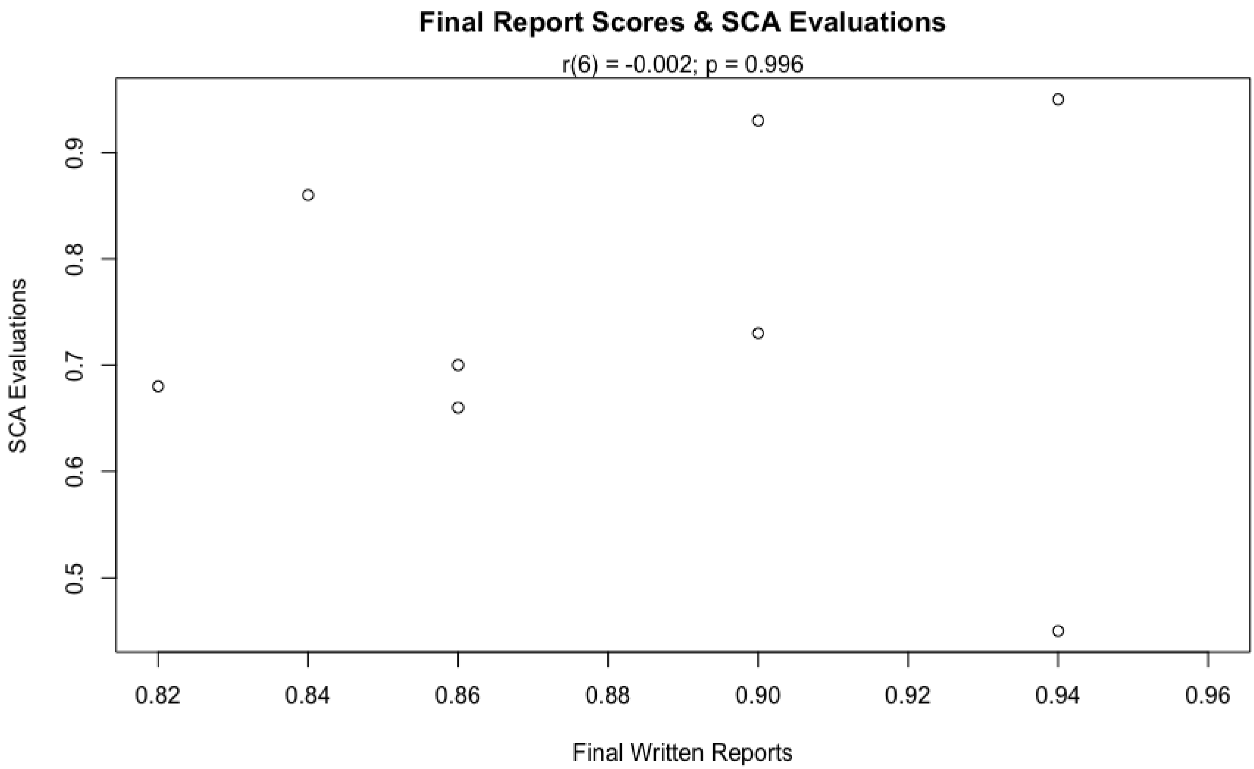

Figure 5. Final Report Scores & SCA Evaluations

That the two variables were uncorrelated corroborates a key conclusion: While students did well on their capstone projects, it may not reflect their ability to conduct sustainability analysis. This makes sense given that the UN SDG assignment mean score was lower by 5 points.

Conclusions

Envision provides a "free-standing assessment tool for comparing sustainability alternatives or to prepare for a more detailed sustainability assessment" [8]. Methodologies laid out in the PMBOK or Agile focus too much on project management skills, like scoping, risk assessment, and scheduling. Discipline-specific bodies of knowledge, like the ASCE BOK, which focuses on civil engineering, is not relevant to computer or mechanical engineering capstone projects. Even if the project directly addresses sustainability, e.g. green infrastructure, solar energy, instructors need shared, streamlined, and ubiquitous criteria on which to evaluate students.

Selection of UN SDGs allowed the design teams to address sustainability in a larger context, the addition of the Envision Rating System helped the teams meet their selected goals in a more localized manner. Using a specific professional rating system as a tool to enhance CE students understanding of sustainability [5]. Applying a rating system, such as Envision, to a capstone project was found to be a useful exercise to help students learn about the rating system but did not provide deeper learning of general sustainability knowledge.

Combining the UN SDGs with Envision provided guidance for students to integrate sustainability into their engineering designs and was hoped to lead to a deeper understanding of sustainability related to infrastructure designs. These two well established frameworks contain global, curriculum-level, and project-level criteria applicable to engineering challenges [6].

Envision looks at sustainability horizontally/infrastructure as compared to LEEDS which focuses on vertical/structural projects. The Envision Rating system by itself may not be sufficient to provide the broad understanding of sustainability concepts in civil engineering practice, but when combined with the UN SDGs the authors hypothesized that a better understanding of sustainability would be achieved [5]. ISI Envision uses a life-cycle assessment approach to measure the sustainability of each project. This includes evaluating the project for its environmental impacts, life-cycle costs, and socio-economic influences and priorities. Specifically, the rating system is divided into the following five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk [8]. Each ISI Envision category has a list of criteria where sustainability credits are accumulated if applicable to a specific infrastructure design. These criteria can also provide guidance into improving a design to make it increasingly more sustainable.

As the designs developed, Students were asked to include specific examples of their sustainability solutions within their project deliverables (page numbers, drawings, discussions, etc.) and to provide justifications for each UN SDGs and Envision credit [6]. They were also required to include sustainability related tasks into their design flowcharts and list of deliverables [9]. The students used individual reflection and group discussions to express their thought process about the sustainable design elements as well as applying best practices and design standards required for each proposed design.

The study concludes and recommends the following:

1. The SCA rubric is useful because instructors' (and mentors') scores will match those of students' scores on sustainability-related assignments, especially if they are not well-instructed in the area. (This case study had students who were instructed on sustainability, yet still performed at levels similar to those of instructors' and mentors' feedback.)
2. At the same time, it measures that students who do well in undergraduate engineering capstone projects do not necessarily do well on sustainability assessments. In other words, grades on sustainability-related assignments will not match grades on engineering design assignments.

3. Further research is necessary to confirm the findings herein and to understand the relationship between grading on sustainability-related assignments relative to capstone assignments. Research should include larger sample sizes, students from all engineering disciplines and from different universities, instructors with different modes of teaching, and more frequent assessment of the SCA and distribution of sustainability-related assignments.
4. Using the SCA throughout the semester and coupling with additional sustainability-related assignments would assist in narrowing the gap between grades in sustainability and the final deliverables for the capstone design.

Recent Developments

To increase accessibility and improve instructors' experience with the SCA, a web-based application, conveniently branded SCA Online, was developed and is currently being beta tested. Running on Heroku's web hosting service, SCA Online allows instructors to use the SCA for multiple courses, store data for those courses, incorporate SCA scores into student grading, and preview summary statistics. A manual is included with SCA Online to provide instructors with a comprehensive, step-by-step user guide.

Users arrive at the landing page and begin by creating their login information, Figure 6. Once they have created an account successfully, they will be directed back to the landing page to log in:

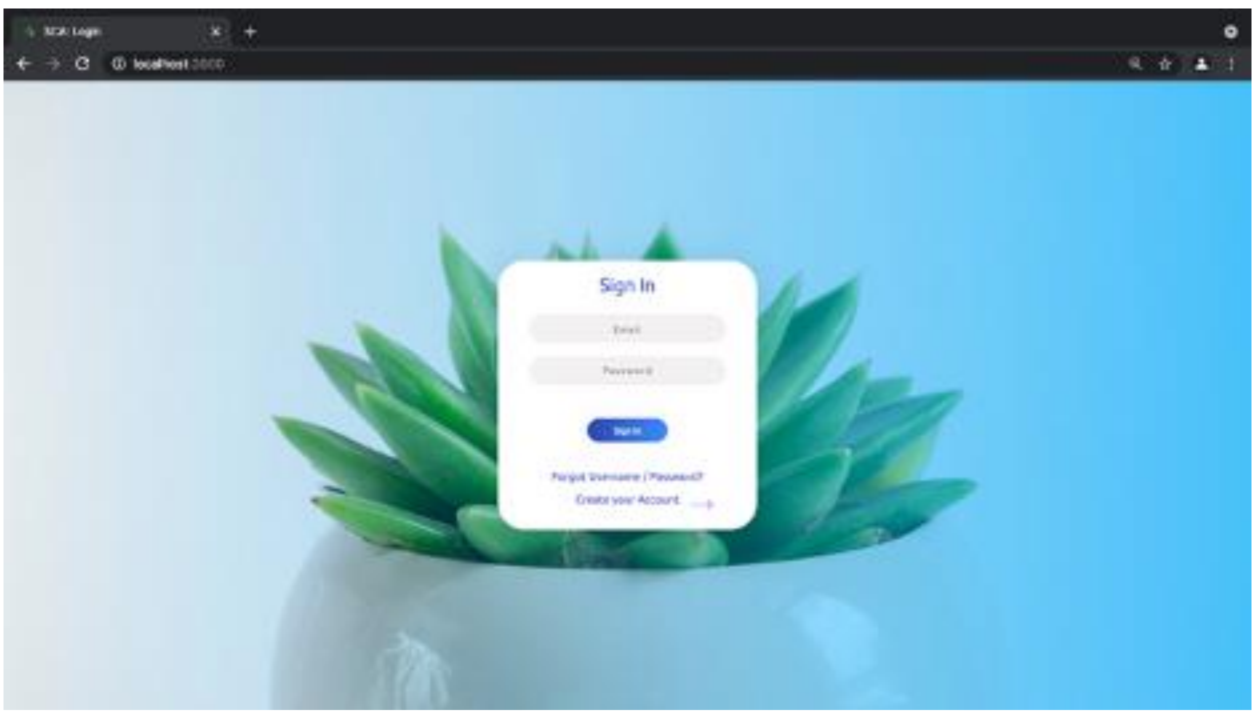

Figure 6. SCA Online Login Page

After logging in, the user enters a page where they can view and manage their courses. Users can create courses with unique ID, title, section, semester, and year, Figure 7. All courses will appear in the right panel: My Courses. Courses can be edited as shown in the left panel.

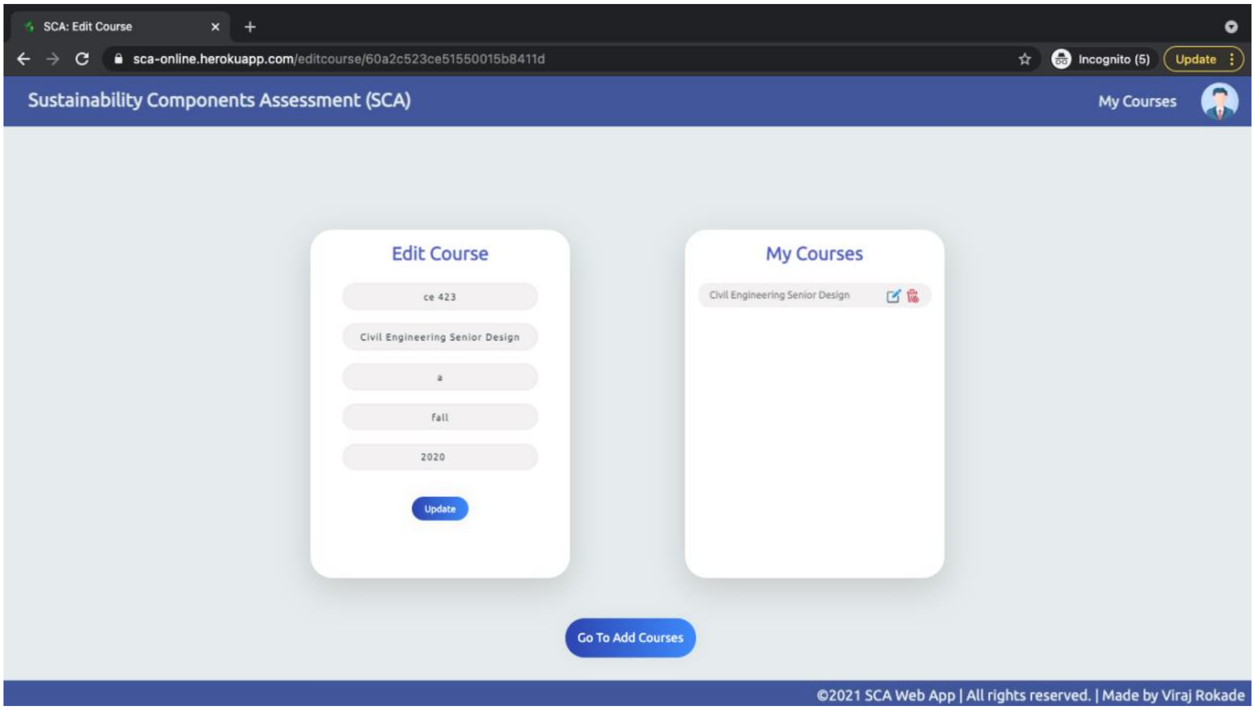

Figure 7. Managing Courses with SCA Online

All courses appear on the My Courses page, Figure 8.

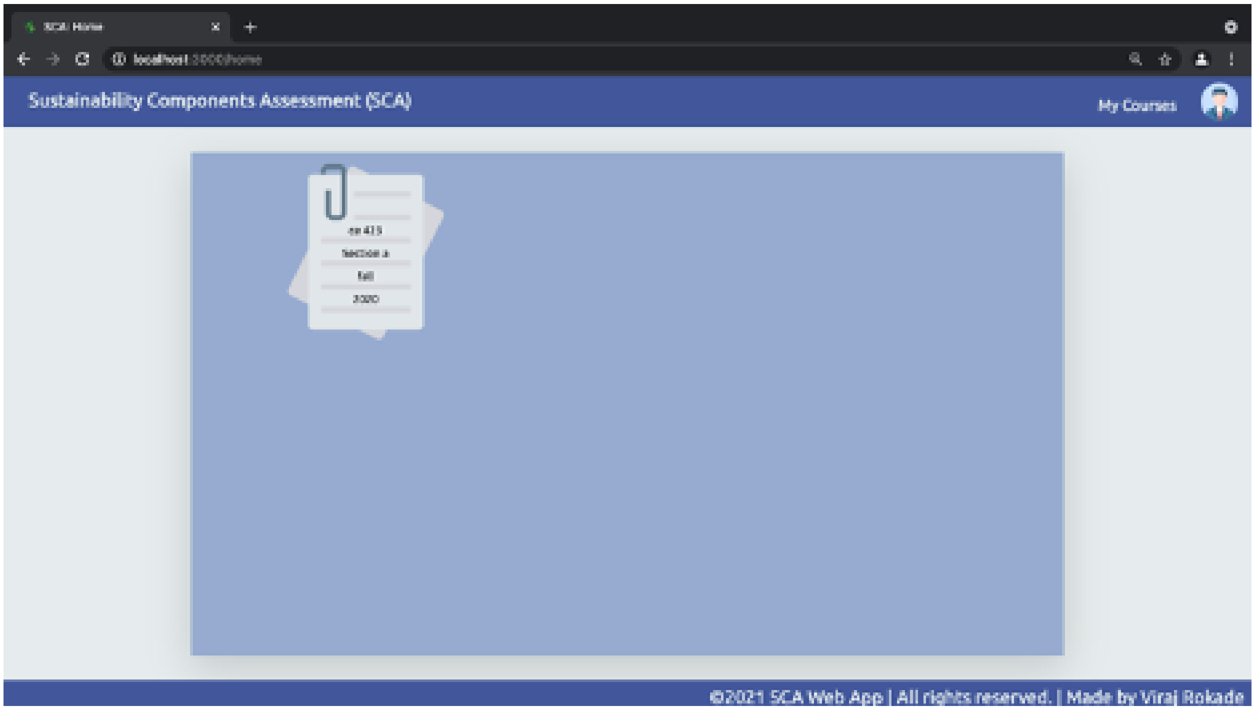

Figure 8. Course Page with SCA Online

Users use the SCA by clicking the icon for a given course to access the dashboard. On the SCA's dashboard, all pertinent information for evaluating student teams or individuals using the SCA is on the right while managing student teams or individuals is on the left panel, Figure 9. Users click "Edit" and "Save" to enter values for each sub-section and can use the bottom panel as a reference to the essential questions and scoring for each sub-section. When users click "Manage," they enter a page for adding, removing, and modifying student teams and individuals, Figure 10.

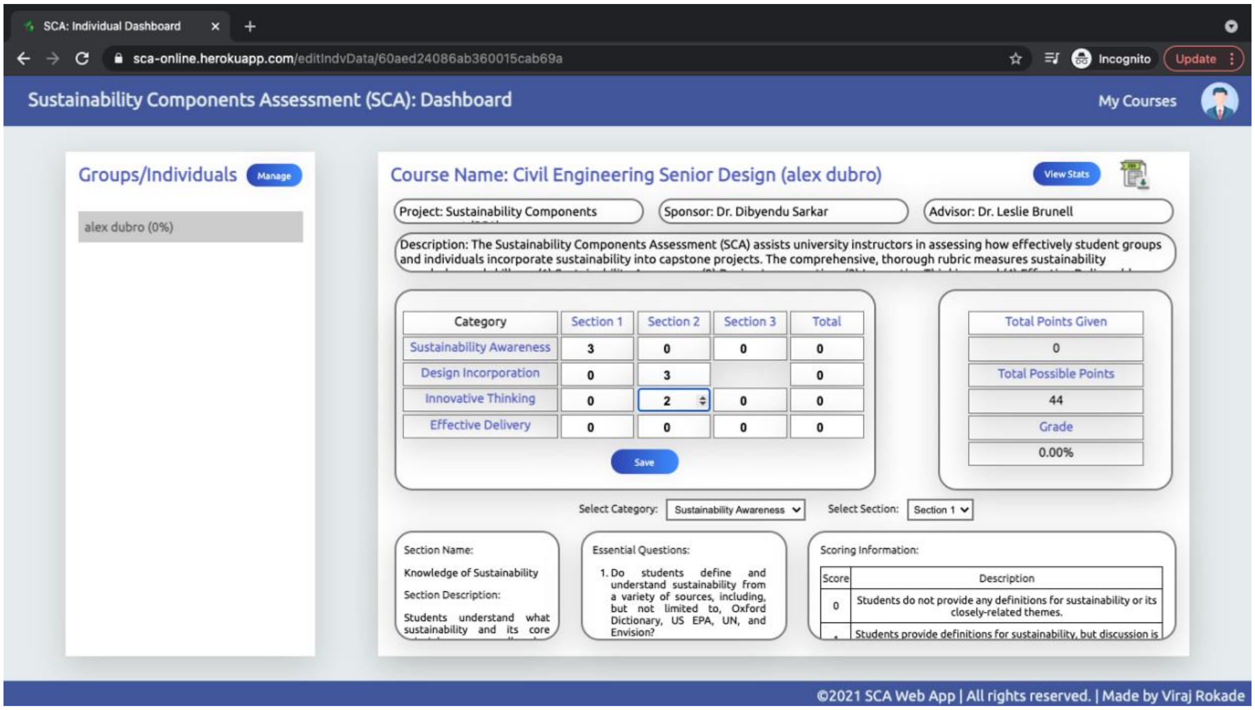

Figure 9. SCA Online Dashboard

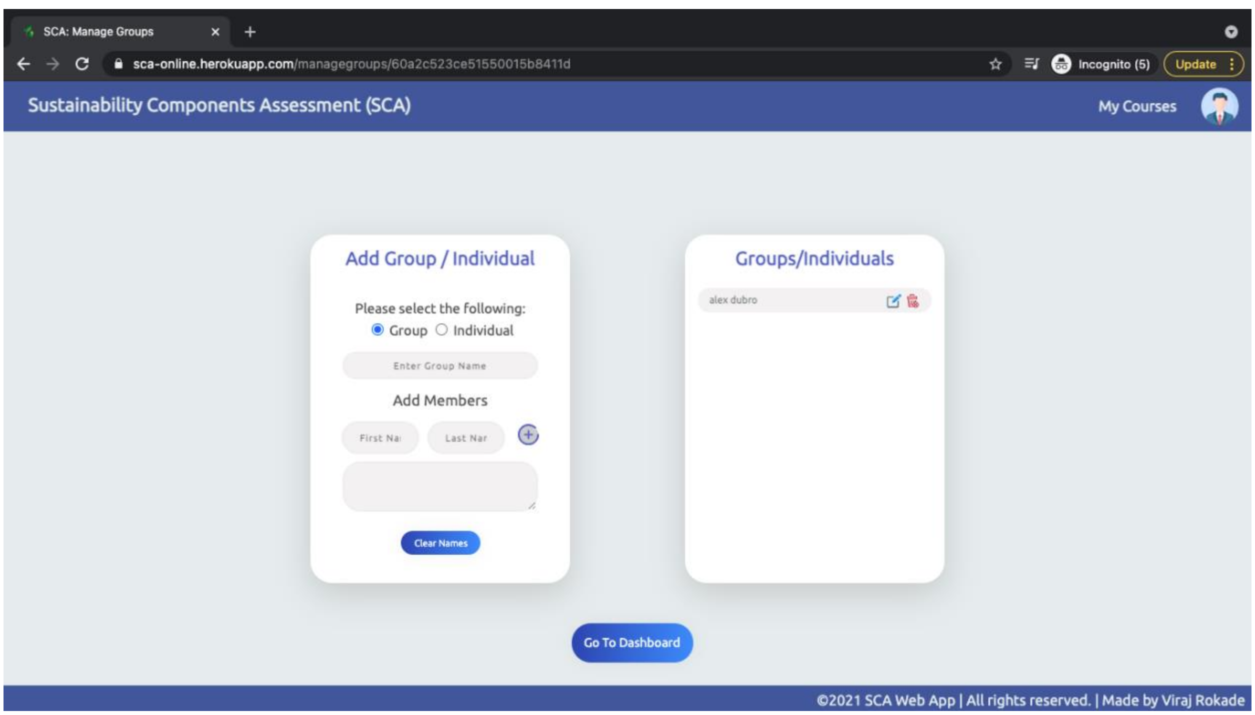

Figure 10. Managing Courses

The SCA Online efficiently keeps track of all key performance indicators (KPIs) for both student teams and individuals. The streamlined, easy-to-use grading system allows for universal coding for grading regardless of the engineering or science discipline of the student team or individual.

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