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Contextualized design projects in graphics and visualization course: Student perceptions and sustainability systems-thinking knowledge

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Introduction and Background

Integrating the United Nations seventeen broad and interconnected Sustainable Development Goals (SDGs) into STEM courses is essential to address global challenges and to increase students' awareness about the link between their subject knowledge and sustainable development. To prepare engineering students with critical perspectives and a deep contextual understanding of sustainability without sacrificing disciplinary rigor is a pressing challenge. Engineering graduates are not typically trained to situate themselves within problem contexts in order to independently frame problem requirements. The key barriers to incorporating sustainable development in engineering education include a crowded curriculum, perceived irrelevance of sustainability content, and limited institutional or external stakeholder commitment.

A number of STEM courses have introduced environmental and social issues through modifications of existing content, or completely new courses. This has probably been most pronounced in engineering, as engineering activities typically involve consumption of energy and resources, and create changes in the physical environment [1]. A growing body of literature is available, addressing and discussing the definition and use of various competences including systems-thinking and critical thinking for sustainable development [2,3] . Systems-thinking is identified as an important learning outcome related to incorporating sustainability in engineering classroom. Additionally, systems-thinking provides an understanding of a system by examining the link and interactions between the elements that comprise the whole system. Sustainability systems-thinking skills include (i) identifying dynamic relationships among ecological, social, and economic factors of sustainability and (ii) understanding the influence of context and stakeholders and (iii) evaluating how design decisions influences the sustainability of communities. To develop a systems-thinking mindset we recently used a higher-order learning outcomes [4] on Bloom's revised taxonomy [5] in a freshman design course with lower three levels of the taxonomy (remember, understand, apply), which consider the elements of systems individually, while to achieve the upper three (analyze, evaluate, create) students must "put things together". At the "analyze" level, students explore the interconnections within a system and study how alterations to one element changes the behavior of the whole. At "evaluate", students are able to compare and contrast alternatives, for example, compare and criticize two proposed solutions to a design problem. By the end of the course, we asked students to "create": they are designing a working system of their own, a new product that considers the economic, societal and environmental systems, and formulates a new solution using their previous knowledge. These opportunities allow students to hone their sustainability-related skills along with the discipline skills by engaging in real-world projects.

This paper presents a socio-technical project-based learning model with a three-tier sustainability intervention that was implemented in a freshman design graphics course. Student perceptions of the interventions as well as assessment results on sustainability systems-thinking skills will be presented. The sustainability interventions in the course include (i) just-in-time lectures to introduce sustainability concepts (ii) technology-in-social contexts activities intended to help students understand how social context can influence the success or failure of an engineering design and (iii) contextualized student projects, which include (a) individual projects that address wasteful human behavior and environmental sustainability in product designs and (b) team projects that address social, environmental and economic sustainability aspects in designing large engineering structures.

The assessment plan includes an investigation of students' a) perceptions of the sustainability-related interventions and b) standing on a set of sustainability-thinking skills. Data on these two outcomes of interest are gathered through the use of end of semester surveys as well as written reflection activities included in student projects. Student survey results are analyzed with descriptive statistics and thematic analysis for open-ended items. Written reflections are scored with institute-developed rubrics tied to each system-thinking skill, depending on the nature of a given reflection prompt. Initial results from thematic analysis of open-ended student survey items suggest that after experiencing the sustainability intervention, students exhibit an initial understanding of the three key components of sustainability: social, economic, and environmental factors. Students mostly perceive the sustainability interventions positively, valuing the opportunity to learn about sustainability and how engineers can design for sustainability. Initial results have informed additions to the survey, with a revised survey designed to further explore student perceptions of the intervention and their sustainability-related learning currently under development for use during the 2019-2020 school year. Scoring of student reflections using institute developed rubrics to assess sustainability-thinking skills is ongoing.

Institute-level initiatives, student learning outcomes and assessment efforts

Georgia Tech is a leading research university committed to improving the human condition through advanced science and technology. While industry partnerships have long been a central part of engineering and technological education through programs such as co-op and capstone design, *community partnerships* – and partnerships aimed at social transformation – have not been central. In fact, they challenge some of the dominant approaches to engineering education, namely, strong emphases on technological innovation and institutional expertise as well as client- and problem-based approaches to partnerships [6]. As a result, in many research university-community partnerships, the university functions as the source of expert knowledge that seeks community partnerships for the purpose of "technology transfer." However, Georgia Tech and a growing number of leading universities are changing that model, seeking to create multi-stakeholder partnerships that co-create systems, processes, and projects for transformative community sustainability [7].

One key way that our university has been advancing this collaborative approach is through its SLS (Serve-Learn-Sustain) Center. This Center was launched in January 2016 to equip students to learn and serve in relation to the theme "creating sustainable communities." The initiative was developed as the university's Quality Enhancement

Plan (QEP), a key component to its reaffirmation of accreditation. The SLS QEP aims to help university students develop the knowledge and capabilities to effectively address sustainability challenges and related community-level societal needs in their professions and their civic lives. The SLS Center facilitates meaningful collaboration between faculty, students, and community partners to embed learning in key sustainability challenges while supporting students' ability to build relationships with diverse stakeholders holding a variety of perspectives and expertise. To achieve these outcomes, the SLS Center emphasizes community engagement and service learning as its central pedagogical approach.

Early in its development, the SLS Center assembled an Assessment Team comprised of university leaders, local assessment experts, faculty and staff, and external consultants to develop Institute-wide Student Learning Outcomes (SLOs) to guide programs and priorities and facilitate assessment. The final set of four SLOs developed were as follows: Students will be able to:

1) Identify relationships among ecological, social, and economic systems.
2) Demonstrate skills needed to work effectively in different types of communities.
3) Evaluate how decisions impact the sustainability of communities.
4) Describe how they can use their discipline to make communities more sustainable.

Initially, SLS center staff and faculty partners assessed student progress toward these learning objectives by collecting data using several different assessment tools. In the Foundation Courses, (some of the Center's Foundation Courses include: Sustainability, Technology, and Policy; Technology and Sustainable Community Development; and Foundations of Sustainable Systems) instructors employed a concept mapping exercise to reveal how students organize and represent their understanding of the interconnectedness of the three sustainability systems--economic, environmental, and social (SLO 1). Investigators compared pre- and post-course concept maps and found a statistically significant increase in the number of concepts, revealing increases in knowledge breadth, depth, and connections between concepts, as a result of the Foundation Course participation. Focus groups of students in Foundation Courses also demonstrated significant progress toward understanding how their disciplinary knowledge and skills could be used to create sustainable communities (SLO 4). In addition to Foundation Courses, assessors collected students' artifacts in a variety of engineering, science, and liberal arts courses related to SLOs 2, 3, and 4 and evaluated progress using the SOLO (Structure of Observed Learning Outcomes) Taxonomy rubric [8]; the average score was 2.76 out of a possible 3.

To create a way to evaluate student learning related to "creating sustainable communities" consistently across all courses, in 2018 the SLS Center developed rubrics for each of the four SLOs and created the Assessment Partners program. In this program, university faculty teaching undergraduate courses collaborate with SLS Center as Assessment Partners to use one of the rubrics, focused on one of the SLS Student

Learning Outcomes, in one of their courses. This approach both enriches student learning and also assists the Center with its assessment needs.

The Assessment Partners program entails three stages. First, faculty partners identify the SLO that most closely aligns with their course learning objectives. They agree to create an assessment for that SLO in their course through an assignment aligned closely with the rubric (exam question(s), project, assignment, etc.) that they can easily share with SLS Center. A Center staff member meets with each faculty partner to review the assignment and ensure that it will work well with the rubric. Student work products for multiple courses aligned with a particular SLO are then scored by a team of SLS staff and faculty partners collaboratively, using the rubric (faculty do not score the work of their own students). In addition to scoring, the sessions build community among faculty with an interest in assessment, as they learn which types of assignments work best to advance different types of learning outcomes and reflect together on how they can improve their courses in the future.

The first step to implement group scoring was a pilot session, held in April 2019, that including scoring of all four student learning outcomes. The pilot session was held to ensure proof of concept for the assessment of student learning. Following that confirmation, in the first subsequent scoring session 13 faculty members representing a wide range of disciplines reviewed a total of 97 artifacts (assessment projects) from 17 courses in disciplines including mechanical engineering, business, public policy, chemistry, city and regional planning, and literature. Scorers used the SLO 1 rubric to evaluate students' ability to identify relationships among ecological, social, and economic systems. For each of five dimensions included in the rubric, scorers chose a performance levels using the following scale: beginning (1), developing (2), competent (3), and accomplished (4). To build consensus about the quality of student work and learning, anchor artifacts were used for scoring calibration and faculty discussion. As the scorers reached consensus, they began scoring independently. In the rare event that two faculty members scored an artifact with notable difference, a third faculty scorer was introduced. Means for the three dimensions ranged from 2.14 to 2.94 (on a 1 to 4 scale).

A process of group reflection resulted in a number of changes in the SLO rubrics and in the Assessment Partners program in subsequent scoring sessions (scheduled for April and May 2020). For example, as a result of experiences in the first session, scorers participating in the next round will receive a clear description of the assignment so they can better evaluate the extent to which students understood the expectation to address the dimensions of the SLO included in the rubric. In addition, faculty feedback following the first scoring session resulted in a formal process the following academic year to meet with each faculty Assessment Partner to enhance alignment between assignment descriptions and the associated rubric. Finally, a question was added to the program application to ensure the assignment would have enough "value" (contribution toward final grade) for students to take it seriously. The freshman graphics and design course discussed in this paper is affiliated with the SLS Center and as part of Assessment Partner program, the post activity reflection artifacts of sustainability intervention activities on (i) technology-in-social contexts activities which are intended to help students understand how social context can influence the success or failure of an engineering design and (iii) contextualized student projects are scheduled for scoring using Center developed rubrics in Spring 2020.

Classroom-level interventions and assessment

Parallel to the institute-level efforts this section briefly describes various interventions undertaken in the SLS center affiliated freshman core course and classroom-level assessment approaches.

Just-in-time Lectures

Just-in-time lectures introduce the concept of sustainability in a clear and structured manner and introduce various terminology related social sustainability, environmental sustainability and economic sustainability. These were explained using case studies highlighting the success or failure of projects based on their consideration and judgement of the impacts of the project on sustainability in the target community. Some of the resources used for this intervention include the Teaching toolkits from the SLS center Additionally, these toolkits provide case studies and other web resources for students to refine their understanding of sustainability and judge the impact of project decisions on sustainability in new situations. All the case studies discussed in class focus on design-for- sustainability. The projects are selected to make students aware of design decisions made to make communities more sustainable. This introduces them to different approaches to design-for-sustainability. It enables them to analyze the design of different products to identify decisions made to promote sustainability.

Technology in Social Context activity

The Technology in Social Context activity provides students with case studies that introduce them to the theme of design-for-social justice. Numerous successful and failed case studies are provided, each with a problem and proposed solution in a different community. These case studies introduce students to the importance of structural conditions in engineering design, identifying stakeholders in a problem and judging who benefits and who suffers from a proposed design solution. The learning from this activity will be later applied in their humanitarian design team projects. Three case studies are briefly included here. The *Global Soap Project* highlights the importance of the identification of roles of different stakeholders and the roles of the members of the community. The *Wind Energy case study* focuses on knowledge sharing, communication, the social character of technical development and power relations and policies. The story about *El Cortito* makes students aware about the ways design can potentially lead to social injustice and that the importance of the considerations mentioned in the other case studies.

Contextualized student projects

Individual projects in the SLS affiliated course address wasteful human behavior and environmental sustainability in product designs. External representation makes implicit information explicit and motivates people to persist with sustainable usage behavior with less cognitive effort. Cognitive effort is required to identify sustainable actions and choices, and then, if one is still motivated, to change one's behavior from current actions and choices to more sustainable ones. Product design with external representations promoting sustainable resource-use can motivate people to make decisions that sustain resources and persist with this behavior. The functions of external representation can be simplified to be meeting complex task constraints, providing motivation and lowering cognitive load [9]. The individual projects assigned to students in the classroom require them to design creative and unique appliances that promote the sustainable use of natural resources for the university community for use either at home or in the office. The product designed by the students is required to have a design with external representations. In alignment with the University's long-term strategic plans for sustainability, students are asked to focus on reducing the use of energy and water resources. The product must have a minimum of four parts and should include creative ideation sketches, part and assembly models, working drawings, post-activity reflections and 3D printed prototype in one of the maker spaces on campus.

The team projects address social, environmental and economic sustainability aspects in designing large engineering structures. The students were given a database of humanitarian design projects to choose from. Teams consists of 4 to 5 members with each student was required to design at least 10 parts and were responsible for a sub-assembly and associated functionality. Additionally, the teams were required to make their solution low-cost, and minimize consumption of depleting natural resources. Teams also tried to make their product multi-functional, which required to identify following engineering-for-social-justice criteria [10]:

1. The problem is identified contextually – involving negotiations between engineering and non-engineering (community, social workers etc.)
2. During design, the structural conditions are identified meeting community needs (who benefits and who suffers)
3. Acknowledging Political Agency/Mobilizing Power (engineers can identify forms of political agency of users, key actors, and their own to mobilize available sources of power to enact a more socially justifiable engineering product)
4. Increasing Opportunities and Resources
5. Reducing Imposed Risks and Harms
6. Enhancing Human Capabilities

The deliverable of team projects included, sub-assembly ideation sketches, part and final assembly in CAD, functional animations and post-activity reflection writeups.

Assessment

A multi-faceted assessment is being undertaken in an attempt to understand the impact of various classroom intervention activities on student learning and perceptions of the course. The larger, institute-level initiative has several student learning outcomes (SLOs), listed in the earlier section, and the primary goal of our assessment is to determine the level of understanding students possess with respect to these learning outcomes. In addition, in cases where use of a pre/post survey instrument is possible, we measure the extent of students' growth in understanding on these learning outcomes over the course of the semester.

In addition to investigating student understanding of these learning outcomes, the assessment effort also seeks to understand student perceptions of the course. More specifically, we investigate student perceptions of both the SLS-related classroom intervention activities themselves, and also the overall benefits and drawbacks to having the course taught with a sustainability focus. The main component of the assessment effort is a student survey that is administered online using a pre/post design. This design allows us to capture student standing on the learning outcomes both prior to and after experiencing the series of SLS-related classroom interventions. Additionally, scoring of various written portions of SLS-related student projects with specially developed rubrics is currently under progress.

Method & Selected Results

Student Survey: 2019-2020 academic year

The student survey the course instructor had been using prior to the 2019-2020 academic year was provided as part of the larger institute-wide initiative. This survey was heavily revised for use beginning in the 2019-2020 school year, primarily in an effort to make it more specifically applicable to the course content, activities, and goals. Due to time constraints related to the survey revisions, it was administered using a post-only design during the Fall, 2019 semester. In the Spring, 2020 semester, it will be administered using a pre-post design, allowing for an analysis of potential changes in student understanding of the SLOs over the course of the semester. Survey items are a combination of newly drafted items, including items from a previous survey developed by the larger institute-wide initiative, and items modified from published instruments (sources specified below).

The student survey begins with items related to students' prior experience, if any, with SLS-affiliated courses, and students' motivation for selecting the SLS-affiliated course. Students are asked a series of open-ended knowledge items corresponding to each of the SLOs, and a rating scale item asking them to report their level of confidence on each of the SLOs. They are then asked to respond to a series of perception-related items about each of the four classroom interventions (i.e., the extent to which they were enjoyable, interesting, useful for teaching engineering content, useful for teaching sustainability content, a valuable use of class time, etc.). Students are asked open-ended items about what they found most and least valuable about the course. A series of items intended to investigate students' perceptions about and the value they place on specific sustainability issues in a variety of contexts concludes the survey [11]. It should be noted that the pre-version of the student survey is far shorter, as it contains none of the general or intervention activity specific perception items, because students would be unable to answer questions about their perceptions of a course and course components they have not yet experienced.

Student Survey: 2017-2018 academic year surveys (selected portions)

A partial analysis of data collected with student surveys prior to the 2019-2020 academic year was undertaken, with the analysis focused on students' general perceptions of the course and basic understanding of the concept of sustainability. These data were collected through open-ended items in the survey. Results from a thematic analysis [12] of student responses to these three selected open-ended items are provided here.

Question: In your own words, define sustainability.
This question was asked in the Fall, 2017 post survey. A total of 16 student responses were received. Five themes were identified in the student responses to this question. Three of the themes entail explicitly discussing one of the three main components of sustainability: social factors, economic factors, and environmental factors. The fourth theme relates to the idea of reusability and/or conservation of one or more types of resources. The fifth and final theme relates to positive impacts, societal/public good, and doing no harm. Sample quotes for each of the themes are provided below.

Themes 1, 2, and 3 (social, economic, and environmental factors)
An approach that involves contemplating positive solutions affecting economic, social, and environmental aspects
Sustainability is the ability of a product to be made without causing detriment to the economy, society, or the ecosystem

Theme 4 (conservation of resources)
Sustainability is the responsible use and allocation of natural resources to minimize depletion of the resource and damage to our planet
Not exhausting resources; not possessing significant burdens on society, the environment, or the economy/producer

Theme 5 (public good/do no harm)
Sustainability is a combination of factors that integrate economic, social, and environmental ideas to reduce harmful side-effects of products and to help improve communities with improved products
Sustainability is the capability of a design or product to have a function with a positive impact on the community and environment

Question: What do you think was most valuable about this course?
This question was asked in both the Fall, 2017 post survey and the Spring, 2018 post survey; a total of 27 student responses were received across these two survey administrations. Four themes were present in student responses to this item. The first relates to seeing value in learning about sustainability and how problem solutions can promote sustainability. The second deals with understanding how engineers can play a role in sustainable design. These first two themes were present in data from surveys across both administrations.

The third theme was present only in the Fall, 2017 survey data; it relates to the more practical consideration of sustainability content being required for students' degree and/or relevant to their future job. The fourth theme, which relates to learning teamwork and management skills through students' work in the class, was present only in the Spring, 2018 survey data. Sample quotes for each theme are provided below.

Theme 1: Learning about sustainability
Learning to solve sustainability issues in a real-world perspective (Fall, 2017)
Being introduced to the basics of sustainability (Fall, 2017)
It gave a perspective not often considered if you haven't taken an SLS course (Fall, 2017)
I think it's valuable because it shines light on sustainability problems that are happening all around the world (Spring, 2018)
Makes you think about all impacts the product will have instead of just making it work with no regard for resources (Spring, 2018)

Theme 2: Engineers' contribution to sustainability; designing for sustainability
Understanding how engineers play a role in creating sustainable communities (Fall, 2017)
This SLS course has given me a new perspective on engineering and the overarching goals on which I should focus. Rather than being separate from the social, political, and economic issues of modern society, engineering coexists with these paradigms and can deeply impact all of them in unexpected ways. (Fall, 2017)
Emphasis on sustainability in design (Spring, 2018)

Theme 3: Major requirement/relevant to future jobs
It was required for my major (Fall, 2017)
The sustainability constraints on projects helps to think in a way that would be relevant to many jobs (Fall, 2017)

Theme 4: Class helped students improve their teamwork and management skills
Group Project; learning to work with a team and being elected project leader by the others gave me a great chance to practice leadership, scheduling, and design-based skills on a project with a sustainable purpose (Spring, 2018)
Learning teamwork and sustainability in a society (Spring, 2018)

Question: What do you think was least valuable about this course?
This question was asked in both the Fall, 2017 and the Spring, 2018 post survey; a total of 26 student responses were received across these two survey administrations. Only one theme emerged from a considerable number of students. This theme, which was present in data from both survey administrations, relates to limits on students' projects imposed by the sustainability requirements, which they felt in some cases limited their ability to be creative and forced them to compromise on their designs.

The other themes were expressed by only one to two students each, and included an excessive workload in the class, too much emphasis on sketching, a lack of real-world examples related to sustainability, an insufficient emphasis on problem solving, complaints about the Lynda modules used for CAD instruction, and a lack of clarity around the sustainability program. Sample quotes for the first theme individually, and all other themes collectively, are provided below.

Theme 1: Limitations on projects imposed by sustainability requirements

We were forced to compromise design to meet the sustainability standards (Fall, 2017)
Sustainability was a big restraint on the type and scope of projects we could do (Fall, 2017)
It limited possibilities for creativity in the individual and team projects (Fall, 2017)

Other themes: overemphasis on sketching; excessive workload; lack of real-world sustainability examples; insufficient emphasis on problem solving; problems with the Lynda modules used for CAD instruction; lack of clarity around sustainability program
I think we could have spent less time on practicing working drawings (Fall, 2017)
Amount of workload (Spring, 2018)
It didn't put as much focus on real life examples as the ideas so it was somewhat tough to see good examples (Fall, 2017)
I think the least valuable part of this course was that we didn't necessarily talk as much about problem solving which I think is needed to form a base about the subject (Spring, 2018)
I found various YouTube tutorials much more beneficial and up-to-date than the Lynda modules we were supposed to watch to learn new CAD skills (Spring, 2018)
At times, the "Serve-Learn-Sustain" initiative seemed to lacked direction and felt vague at best (Fall, 2017)

<u>Concluding Remarks</u>
A socio-technical project-based learning model with a three-tier sustainability intervention strategy, implemented in a freshman design graphics course, is presented. A multi-faceted assessment is presented to understand the impact of various classroom intervention activities on student learning and perceptions of the course. Institute-level assessment efforts, including scoring of student post-activity reflections, using SLS Center developed rubrics for each of the four SLOs is also presented to assess sustainability systems-thinking skills.

The sample results from post-survey data collected during the 2017-2018 school year indicate that students are, for the most part, able to provide one or more of the three key sustainability components in their self-generated definitions of sustainability: economic, environmental, and social factors. In their definitions of sustainability, students also provided definitional components related to conservation of resources, as well as serving the public good and doing no harm. The opportunity to learn about sustainability and apply it to design within their discipline was the most often-cited positive aspect of the class, while limits on their creativity and selection of design projects as a result of complying with the sustainability focus of assignments was the most frequently cited negative aspect of the class.

We have heavily expanded and modified the student survey for the 2019-2020 school year. It now includes items about students' prior experience with SLS coursework, specific items assessing student perceptions of various aspects of the SLS-related activities, and a modified version of a published instrument measuring student values and beliefs related to sustainability. To assess student understanding of and confidence around the sustainability content delivered throughout the course, students will also answer a series of open-ended items about sustainability topics, as well as rate their level of confidence on these topics. We anticipate that this new survey will provide more robust evidence on students' perceptions of and student learning within the SLS version of this introductory mechanical engineering design course.

As described above, assessment of progress toward sustainability learning objectives in this course is part of a larger, campus-wide initiative to assess the impact of the Serve-Learn-Sustain program on undergraduate student learning. In future, the implementation of SLS concepts and skills in this introductory engineering course will continue to contribute to expanded Scholarship of Teaching and Learning (SOTL) research at this institution. For example, the interventions described in this paper differ in some respects from the kinds of sustainability interventions that have been undertaken in other courses, both within and outside of engineering education. Future campus-wide assessment efforts may compare and contrast the impacts on student understanding and skills of alternatives kinds of interventions. The rich history of assessment data in this course will help inform the kinds of SOTL research undertaken more broadly at Georgia Tech. In addition, the interventions and assessment tools described here will be expanded through the use of a broad Education for Sustainable Development (ESD) framework that draws upon cross-cutting competencies developed by the UNESCO program on ESD. This step will allow for comparison between the institution described here and others around the world using the UNESCO framework.

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