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Identifying Students' Sustainability Preferences to Improve Design Team Performance

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Abstract

In this paper, we discuss evidence from two studies, which use a mix of individual and team tasks to uncover students' knowledge and skills related to sustainable design. The research explores two questions: (1) Could a team with a mix of individual student sustainability profiles influence individual team members' learning? (2) Does a diverse, balanced team enhance project performance? When we look at individual students, preferences or affinities emerge that indicate socially-, environmentally-, economically-, or technically-minded individuals. As part of a team, students influence each other's design decisions, often by bringing new knowledge or a different perspective into a discussion. Team composition that prioritizes a mix of individual preferences could be a valuable strategy for sustainable design, and help team members appreciate the value of different sustainability aspects.

1 Introduction

Typical sustainable development frameworks emphasize pursuit of at least three objectives: social equity/quality of life, environmental protection/restoration, and economic vitality. In theory, sustainable design seeks harmony among all objectives, although in reality designers make trade-offs to achieve technical objectives or stakeholder approval. We have conducted various studies to understand how engineering students conceptualize and apply sustainability principles to make design decisions. While examining how students perform and develop cognitive flexibility on sustainability-related tasks, we have made interesting, and at times unexpected, observations of individual and group behaviours. In particular, in studies involving concept mapping and application of a design rubric, we noted that students tend to focus on one or two aspects of sustainability. At the group level, engineering students seem to undervalue the economic dimension and, depending on the student population, over-represent either social or environmental dimensions. This observation has been well-documented and assumes that students ideally should develop a balanced understanding of sustainability pillars. When we look at individual students, profiles emerge that indicate socially-, environmentally-, economically-, or technically-minded individuals.

This exploratory work is guided by two questions: (1) Could a team with a mix of individual student sustainability profiles influence individual team members' learning? (2) Does a diverse, balanced team enhance project performance? Our paper examines these questions starting with the literature on sustainability attitudes/behaviors and engineering team formation/performance. We then describe our previous studies that led to these questions and provide preliminary findings that merit further investigation.

2 Background Literature

2.1 Student Attitudes about Sustainability

The *Nature Sustainability* Expert Panel (2019) observed that "Design behaviour for sustainability is part of an interdependent network of judgments and decisions that are shaped by specific professional and socioeconomic contexts and that must consider both existing and preferred states of complex Anthropocene situations." Individual and interpersonal factors, among others, can significantly impact design behaviour toward or away from sustainability. A key challenge is that designers' mental models must accommodate the range and interdependencies of multiple factors that influence human behaviour, including cognitive biases. Individuals bring different mental models to a task, which results in different weighting of quantitative and qualitative decision factors (The *Nature Sustainability* Expert Panel, 2019). This challenge affects both student and professional designers and teams.

Research shows that students exposed to sustainability-related problems during their education are more likely to want to tackle those types of challenges in their career (Shealy et al., 2015) and engineering experiences related to sustainability may help broaden participation in engineering programs and career paths (Klotz et al., 2014). Survey and other self-report instruments are a common approach for understanding student attitudes and behaviours. For example, Shealy et al. (2017) developed and piloted a new survey instrument to measure undergraduate engineering students' climate change literacy, their engineering identity, career motivations, and agency to address sustainability through engineering. According to critical engineering agency theory, the opportunity to make real change in their world leads to increases in students' learning and interest in engineering, and in this case to take action to reduce climate change impacts and support sustainability (Shealy et al., 2017). Perrault and Scott (2017) found through an online survey that an effective way to influence college students' behavioural intentions toward sustainability is to combine fear inducing messages about sustainability threats with messages that will increase students' self-efficacy. Whitley et al. (2016) demonstrated that values are a strong predictor of sustainability behaviour among college students and observed the importance of this finding because undergraduate students are susceptible to changes in their values, beliefs, and norms during their college years. Using multivariate analysis and direct measures, Svanström and colleagues showed that students' demonstrated learning of sustainable development concepts can be influenced by their backgrounds, participation in different learning activities, and the type of assessment used to capture learning (Svanström et al., 2018). All of these studies help inform educational practices and environments that encourage individual students to act more sustainably in their personal and professional lives.

2.2 Design Teams and Formation

Maximizing the effectiveness of engineering teams has been the focus of volumes of research, including many interdisciplinary and multidisciplinary studies (see Borrego et al., 2013 for such a review). This research has focused on both professional teams and student teams (Little & Hoel, 2011). Early team effectiveness studies largely focused on the most effective methods for building teams across disciplines with a focus on how disciplinarily diverse teams impact outcomes related to both the team process and the quality of the product produced by the team. Over the decades research on the effectiveness of teams has moved to examining other types of diversity within teams, including cognitive differences. Mello and Rentsch (2015) examined the vast literature around the broad and complicated concept of cognitive

diversity. Other researchers have examined the impact of cognitive diversity related to specific team outcomes such as creativity (Wang et al., 2016). Culp and Smith (2001) moved beyond cognitive diversity to examine the impact of different personality approaches on engineering projects. The researchers concluded that "project teams can increase their chances of success by understanding and capitalizing on different behavioural styles related to psychological types" (p. 33). Numerous team formation approaches have been developed and tested to optimize engineering team performance. For example, balancing students' preferred team roles (Henry & Stevens, 1999) or accounting for multiple criteria using a web-based tool (Layton et al., 2010). However, none of these studies have examined the impact of how different engineers with different foci (Ecological, Social, Economic, or Technical) impact the engineering team process and outcomes. Rather than assign teams based on complementary technical skills or teamwork styles, might we form teams with cognitive diversity related to sustainability?

3 Methods

3.1 Concept Mapping Study

Concept maps were developed in 1972 by J. Novak as a way to track changes in children's mental models of science (Novak & Musonda, 1991). Since Novak's original work, concept maps have been used frequently as assessment tools in engineering education, including for tasks related to sustainability (e.g., Watson et al., 2016). One goal for concept mapping is to allow students to represent their mental models in a tangible way. In a previous study, 23 engineering (n = 8) and non-engineering (n = 15) students at a mid-sized U.S. public university completed two listing and two concept mapping tasks in one of four randomly assigned sequences while wearing an electroencephalograph (EEG) cap to quantify cognitive workload. Our study was designed in collaboration with a research team at a U.S. public research university (Hu et al., 2019). Students were prompted to create concept maps and lists related to four topics: Water Availability, Climate Change, Food Sustainability, and Renewable Energy. These topics were randomly assigned so that each participant saw all four topics and made concept maps on either Water Availability and Climate Change or Food Sustainability and Renewable Energy. Students created lists for the other two topics. More details on the research design can be found in previous publications (Barrella et al., 2018). This paper focuses on the concept map scores.

Many scoring methods have been used to evaluate concept maps, and we used one quantitative and one qualitative scoring approach: the Traditional Method and Categorical Method (see Watson et al., 2016), respectively. This paper will focus on our results from the Categorical Method which analyses the frequency and interconnectedness of different categories of concepts. Scoring a concept map with the Categorical Method requires the scorer to first categorize each concept, and for this study each concept was assigned to either the Environmental, Social, Economic, or Technical category. After categorization, the concept map is scored based upon number of interconnections between different categories. In this study, two researchers independently categorized all concepts for each concept map before meeting to compare scores, and interrater reliability was determined from Cohen's Kappa. The agreement between scores was generally high with Kappa's of 0.78, 0.67, 0.60, and 0.57 for concept maps related to Climate Change, Water Availability, Food Sustainability and Renewable Energy respectively. All analysis was completed using consensus scores that the two researchers agreed upon after discussion.

3.2 Rubric Study

In a second study, 51 junior engineering students from two course sections of capstone design at the same mid-sized public university evaluated their capstone projects with a new Sustainable Design Rubric (see Table 1 for criteria). Each student belonged to one of fifteen capstone teams and was assigned to evaluate their projects against a randomly assigned subset of rubric criteria. Capstone teams then completed a consensus process to arrive at a final rating for each criterion. In addition to calculating descriptive statistics for individual and team scores, we also reviewed correlations between criteria and evaluated the quality of students' evidence for their ratings. The methods for this study are described in Barrella et al., 2019.

Table 1: Criteria composing the Sustainable Design Rubric (Barrella et al., 2019).

1.	Minimizes the use of non-replenishable raw materials; requires minimal energy input or uses renewable energy sources
2.	Minimizes quantity of consumable waste (e.g., water, materials) output; manages quantity and quality (benign, usefulness) of waste
3.	Protects or enhances natural ecosystems (water, air, soils, flora, fauna, etc.)
4.	Identifies and engages stakeholders (external to project team) in the design process
5.	Addresses needs of diverse stakeholders, acknowledging culture and other differences among individuals and groups
6.	Protects human health and physical safety of users and society
7.	Promotes human well-being and enhances quality of life for users and society
8.	Evaluates economic impacts of environmental design criterion
9.	Evaluates economic impacts of a social design criterion
10.	Considers affordability for users and/or demonstrates cost competitiveness or cost reduction for client/sponsor
11.	Evaluates economic costs and benefits to inform decisions
12.	Final design impacted by trade-offs among environmental, social, and economic criteria and reflects balance of dimensions
13.	Uses and/or creates innovation(s) in its specific field to achieve sustainability
14.	Worked with experts from other disciplines (i.e., outside engineering) to enhance process or final design

4 Results and Findings

4.1 Profiles Emerging from Concept Map Study

Student preferences emerged through categorical scores demonstrating depth in one or two sustainability categories, with less emphasis on other categories. In total, participants' concept maps included 41% Ecological, 21% Social, 7% Economic, and 31% Technical concepts. We observed significant variations across students. For example, one participant's breakdown was 72% Ecological, 16% Social, 0% Economic, and 12% Technical, whereas another's was 7% Ecological, 19% Social, 15% Economic, and 59% Technical. If a student devoted at least one third of their concepts to a category, they were defined as having an affinity for that category. Most students' concept maps demonstrated an affinity for one or two categories. Frequently, students displayed a tendency to overall emphasize a single aspect of sustainability. Only two concept maps from distinct participants showed no affinity for any category. Even in cases where students had split affinities between their two concept maps, each map was likely to have a high affinity for at least one category. Approximately 78% percent of concept maps included at least one category accounting for greater than or equal to 50% of the concepts for that map. Of these high affinity concept maps, there were

three instances of 100% affinity. Among these high affinity scores, the mean percentage of concepts belonging to one category was 67%.

Student concept maps were classified according to their primary affinity. Half points were awarded to a category when the concept map demonstrated split affinities with the same number of concepts in two categories. As shown in Figure 1A, student affinities with Ecological, Social, Economic, and Technical categories were 21.5, 8.0, 2.5, and 20 concept maps respectively. There were 54 concept maps overall, and two concept maps showed no affinity. If a student had an affinity for a certain category in their first concept map, they were more likely to have an affinity for that category in their second concept map. Students who showed an affinity for the same category in both concept maps made up 59% of the sample.

In addition to analysing differences across students, we also observed differences in concept distributions across sustainability prompts (Figure 1B). One notable trend was that concepts from renewable energy concept maps showed the most technical concepts. The strong technical affinity for the renewable energy prompt may be due to current economic emphasis on developing new or more efficient technologies to compete with fossil-fuels. Water availability and climate change showed a similar composition of concepts between the four categories. While individual students showed similar affinities across concept mapping tasks, those affinities can be influenced by the problem context.

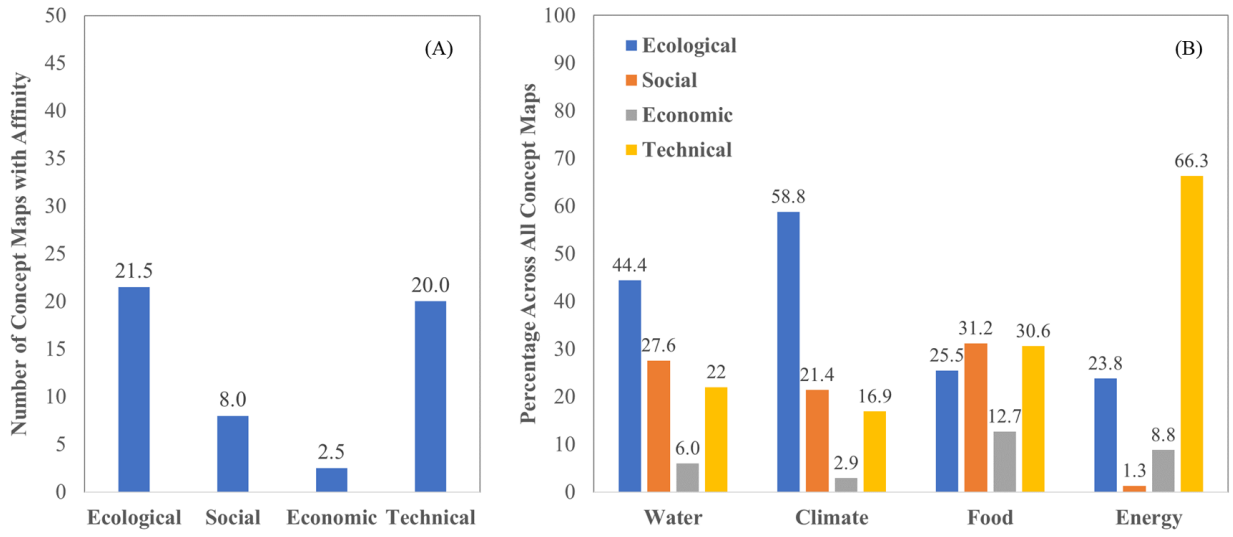


Figure 1: (A) Distribution of student affinities (defined as devoting 33.3% or more of total concepts in a concept map to a category). (B) Distribution of concepts across categories by concept map topic (water availability, climate change, food sustainability, or renewable energy).

4.2 Individual and team performance from Rubric Study

After completing individual and team scoring of their design projects using the Sustainable Design Rubric (see criteria in Table 1), students indicated that consensus discussions with their teams were beneficial and often introduced them to perspectives that they had not considered. Discussions often led to a change in score compared to one or more of the student reviewers and/or provided additional evidence for consensus scores (Table 2). Also, most students identified areas for additional learning or project improvement as a

result of consensus scoring. We are finding similar results from an unpublished study involving a different student population.

Table 1: *Mean individual and consensus scores by criterion.* (Adapted from Barrella et al., 2019)[1]

Criterion	**Individual *M* (*SD*)**	**Consensus *M***
Env1: Non-replenishable resources	1.53 (.78)	1.73
Env2: Waste	1.56 (.86)	1.73
Env3: Ecosystem protection	1.43 (.82)	1.33
Soc1: Stakeholder engagement	2.56 (.50)	2.67
Soc2: Diverse cultures and needs	1.68 (.75)	1.67
Soc3: Human health/safety	2.09 (.69)	2.40
Soc4: Quality of life	2.41 (.71)	2.67
Econ1: Economic/environment	1.55 (.95)	1.53
Econ2: Economic/social	1.62 (.90)	1.93
Econ3: Affordability, cost competitiveness	2.10 (.82)	2.13
Econ4: Costs and benefits	1.61 (.89)	1.73
Trade-offs	1.57 (1.08)	1.73
Innovations in field	1.97 (.96)	1.87
Interdisciplinary experts	1.77 (.94)	1.80

[1]Shaded cells indicate a perceptible change between mean individual and consensus scores.

5 Implications for Team Formation

Previous studies involving other groups of engineering students have also revealed individual student affinities, often toward either environmental or social aspects (Watson & Barrella, 2016). Also consistent with prior studies (see Barrella & Watson, 2018), the economic category was underrepresented in the concept maps with just over a tenth of the representation of the Ecological and Technical categories. The social orientation was lower than expected based on prior studies involving the same engineering student population and considering the mix of engineering and non-engineering majors.

We recognize that our evidence is limited by the scope of the original studies which did not directly investigate how individual student sustainability competencies and preferences impacted team performance. However, our observations lead to interesting research questions that we would like to investigate. For example, rather than emphasize each student demonstrating mastery of sustainability concepts across the different domains, could we help faculty and students become aware of individual strengths and predispositions and identify complementary teammates? We would still expect students to need a basic understanding of sustainable design and factors related to environment, economy, and society so that they are open to working with teammates who bring different knowledge and skills in each area.

Numerous approaches from the literature could be used to identify student affinities (e.g., survey instruments, student essay, concept maps). How might this diversity of experience with sustainability concepts trade-off with other personal factors that could enhance or limit a team's performance? We would not want affinities to lead to unmanageable conflict (Mitchell et al., 2009). Our goal would be studying how sustainability profiles may assist with team formation and improve performance on sustainable design tasks.

We hypothesize that exposing individuals' cognitive biases with respect to sustainability and balancing team composition across affinities could improve team performance on a design project.

6 Conclusions

Individual student and collective team knowledge, skills, and work styles are important factors in team performance. Based on preliminary analysis, team composition that prioritizes a mix of individual affinities could be a valuable strategy for sustainable design, and help team members appreciate the value of different sustainability aspects. Future work could have implications for both student and professional design teams, particularly if combined with activities to help team members identify their cognitive biases with respect to sustainability and to utilize the team's diversity of thought.

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