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How Cognitive Development Affects Student Perception by Threading Sustainability through Civil and Environmental Engineering Curriculum

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Abstract

As environmental, social, and economic systems grow in complexity, we need to fully understand the impacts that engineers and scientists have on the world around them. To better prepare students to understand the sustainability dimensions and tackle the challenges of real-world problems, a strategic approach has been implemented to incorporate sustainable design principles throughout the four-year undergraduate curriculum in civil and environmental engineering. To set a foundation of sustainability upon which students could build throughout their academic career, this approach involves intentionally threading sustainability concepts and applications through various courses in the required curriculum. During the first two years, an awareness of sustainable design is created in a required first-year introduction to design course, followed by higher-level learning of the science of sustainability and applying sustainability principles in a required sophomore-level course. The students are then prepared to address environmental, social, and economic impacts of projects in their civil engineering technical design courses during the third-year curriculum. In their fourth year, students apply sustainable design principles and develop sustainability metrics upon which to evaluate design solutions during their senior capstone design course.

With this approach, learning occurs not within a single course but across several courses spanning the four-year curriculum. The threads of learning approach allows faculty to incorporate sustainability into technical design courses, which provides students a more continuous exposure to understanding impacts of their design decisions and creating value in the broader, holistic perspective of engineering projects.

Assessment of student learning involved pre- and post-surveys at the beginning and end their four-year academic careers in the civil and environmental engineering curriculum. Students rated their opinions of the importance of various knowledge and skill sets to the engineering profession, as well as their confidence in addressing environmental, social, and economic aspects of engineering projects. This paper investigates how the cognitive development of incorporating sustainable design principles into engineering design problems as a thread of learning through the curriculum has affected students' perceptions of sustainability in their broader understanding of engineering professions.

1 Introduction

Sustainable development was coined by the Report of the World Commission on Environment and Development: Our Common Future in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Since then the United Nations (UN) adopted 17 Sustainable Development Goals (SDGs) at the UN Sustainable

Development Summit in 2015 (UNGA, 2015). These SDGs, including issues related to poverty and hunger, availability of clean water and sanitation, sustainable cities and communities, and clean energy, are supported by the Division of Sustainable Development Goals within the UN. Key SDGs related to civil and environmental engineering include clean water and sanitation, sustainable cities and communities, life below water, and life on land, for example (UNGA, 2015). Additionally, the United States National Academy of Engineering (NAE) Grand Challenges for Engineering identified 14 goals for improving life in the 21st century. Some of these goals coincide with SDGs, including access to clean water, infrastructure, and economical sources of alternative energy (NAE, 2017).

In order to educate engineers in a way that instills confidence to tackle such complex and wicked challenges they may face in their career, it is important to include sustainable development as "just good engineering" (Sutter *et al.*, 2012) and as an integral component of their engineering education throughout the entire undergraduate curriculum.

2 Strategic Approach

To better prepare students to understand the sustainability dimensions and tackle the challenges of real-world problems, a strategic approach has been implemented to incorporate sustainable design principles as a thread of learning throughout the four-year undergraduate curriculum in civil and environmental engineering. During an introduction to design course taught in Year 1, students are introduced to sustainable design techniques to create an awareness of sustainability in engineering design. Through touch points of discussion in weekly lectures and through weekly reading assignments, students are exposed to the concept of the triple-bottom line and assessing social, economic, and environmental impacts of engineering design.

In Year 2, students take a required course in sustainable civil engineering. The first part of this course focuses on the science of sustainability, with coverage of biogeochemical cycles and global energy balance. The second part of the course emphasizes how to apply and measure sustainability in engineering design through life cycle assessments, systems thinking, resiliency, social impacts, sustainability indicators and metrics, and sustainability rating systems. Assessment of student learning showed improvement in students' abilities to comprehend principles of sustainable design as set forth during Years 1 and 2 (Mueller and Robinson, 2015). For example, even in the initial years of incorporating sustainability into Years 1 and 2, students' definitions of sustainable development grew from simplistic responses related to longevity and being "earth-friendly" to more substantive discussions of the triple bottom line, life-cycle thinking, and designs that are not only "beneficial for today's generation, but for generations to come" (Robinson and Mueller, 2013).

In Year 3, sustainable design principles are reinforced in required technical civil and environmental engineering courses. For example, students in a structural mechanics course assess social, economic, and environmental impacts of a structural design problem. Students work on engineering designs related to urban stormwater management in a water resources engineering course and to nutrient removal in wastewater treatment in an environmental engineering course. Both are examples of design applications of global biogeochemical cycles discussed in CE250.

By Year 4, students are prepared to incorporate sustainable design principles in their capstone design projects and assess sustainability in their design by tracking performance indicators. A module on community engagement was also added in a required codes and regulations course in Year 4 that focuses on social sustainability through analysis of case studies from a variety of countries and cultures (Marincel Payne and Aidoo, 2017). As part of the concept development phase of senior capstone design, students are guided through a holistic approach to view the full perspective of their project to develop purpose and vision statements, as well as overall design objectives (Mueller, 2018). While working on their technical design components, students create sustainability metrics and performance indicators, such as area of land impacted by new trail alignment or area of social space in a building design, that they use as tools to measure sustainability in their design (Mueller and Robinson, 2015).

3 Results

Assessment of student learning involved pre- and post-surveys at the beginning and end their four-year academic careers in the civil and environmental engineering curriculum. The survey had two parts: rating confidence in personal ability to perform the stated tasks related to addressing sustainable development on an engineering design project and rating the level to which they agree or disagree to statements relating to the importance of sustainability in general and sustainable design in the engineering profession (McCormick *et al*., 2015). These surveys were administered at the start of fall quarter, the beginning of the academic year for Year 1 students and at the end of spring quarter, the end of the academic year, for Year 4 students to assess cognitive development in sustainable design and affective development in sustainability over the four-year curriculum.

The first part of the survey involved statements in which students rated their degree of confidence to perform the tasks stated on a scale of 1-11 (1 = 0% confidence, 6 = 50% confidence, and 11= 100% confidence). The second part of the survey involved statements in which students rated the level to which they agreed or disagreed on a scale of 1-7 (1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, 7 = strongly disagree).

Survey results were separated into responses from Year 1 students and responses from Year 4 students and were aggregated for three years of data collection: AY2016-17, AY2017-18, AY2018-19. The goal was to observe any changes in ability to achieve tasks related to sustainable design through the four-year curriculum on a general aggregate basis without longitudinally tracking each student cohort. The second goal was to observe any changes in perception of value and importance in sustainability and sustainable development.

Results from the first part of the survey show that mean ratings of confidence in achieving sustainable design tasks increased over the four-year curriculum (Table 1; Figure 1), with mean ratings showing around 50-60% confidence at the start of Year 1 to mean ratings showing around 80-90% confidence at the end of Year 4 for all tasks. This shows that students' perceived ability in achieving the tasks grew, which reflects on the cognitive development of learning the knowledge need to achieve said tasks. Results from the second part of the survey show that affective development did not follow cognitive development (Table 1; Figure 2). Mean ratings decreased slightly for all statements with ratings ranging from slight disagreement to agreement overall.

Table 1: Comparing responses from all Year 1 students with all Year 4 students for AY2016-17, 2017-18, and 2018-19. SD = standard deviation (survey questions from McCormick *et al.* 2015)

		Year 1 (n=71)		Year 4 (n=83)	
		Mean	SD	Mean	SD
Confidence in Ability: scale 1-11 (none – 100%)	Identify the environmental elements of an engineering project	6.06	2.41	9.06	1.47
	Understand environmental risks associated with engineering projects	6.38	2.39	8.95	1.48
	Identify the economic elements of an engineering project	6.31	2.38	9.25	1.32
	Understand the economic risks associated with engineering projects	6.30	2.33	9.22	1.34
	Identify the social elements of an engineering project	6.30	2.42	9.13	1.32
	Understand the social risks associated with engineering projects	6.10	2.34	9.10	1.39
	Recognize the social and economic impacts in engineering design	6.41	2.32	9.17	1.26
	Understand the interdependency among environmental, social, and economic aspects of engineering	6.34	2.29	9.33	1.33
	Assess the practicality of engineering design, including the potential impacts on community and economy	6.31	2.37	9.20	1.42
	Understand the meaning and application of sustainable engineering	6.21	2.44	9.24	1.39
Value Perception: scale 1-7 (strongly disagree - strongly agree)	It is important for me to learn how engineers can make the world more sustainable.	6.14	1.00	5.73	1.21
	Engineers play an important role in improving overall quality of life.	6.52	0.78	6.12	0.92
	The ability to assess social, economic, and environmental implications of engineering designs is a useful skill to help me be successful at my job.	6.23	0.95	5.63	1.25
	I would prefer to learn about sustainability engineering applications more than many other engineering concepts.	3.94	1.29	3.60	1.61
	I typically read news stories involving environmental, energy, and economic issues before reading other news stories.	4.18	1.59	3.83	1.78
	If income was not a factor, I would prefer a job related to sustainable development over other types of engineering positions.	3.83	1.65	3.41	1.73
	I have volunteered (or am planning to volunteer) on a project to help a community become more sustainable.	4.80	1.62	4.33	1.76
	I engage others in conversations and activities to heighten awareness of recycling, environmental protection, or sustainability principles.	3.99	1.70	3.80	1.60
	Practicing sustainability is a behavior that is a part of my everyday life.	4.68	1.49	4.49	1.43
	My future career will likely involve solving local or global problems that may involve social, economic, and environmental issues.	5.32	1.58	5.13	1.44

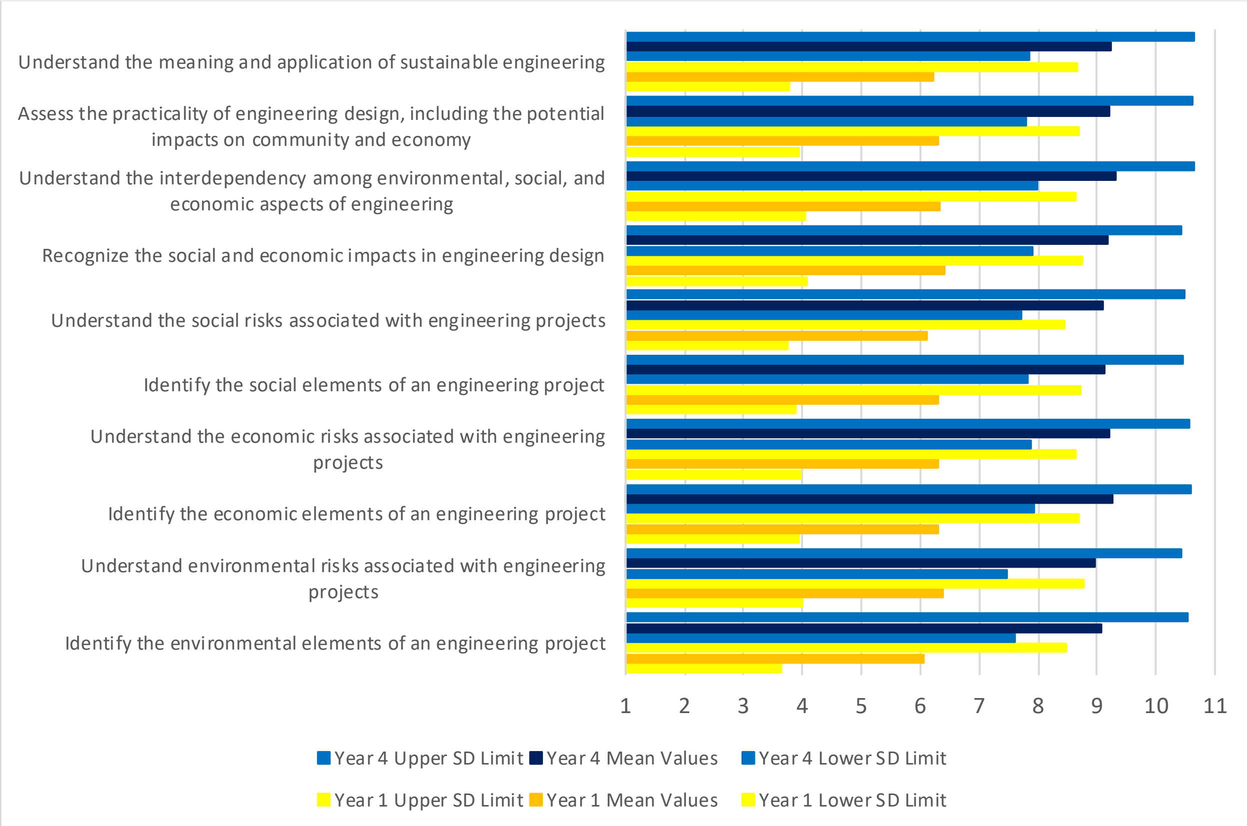

Figure 1: Ratings on a scale of 1 (not confident) to 11 (fully confident) of confidence in abilities related to addressing sustainable design on an engineering project from AY2016-17, 2017-18, and 2018-19; SD = standard deviation; Year 1 n=71, Year 4 n=83 (survey questions from McCormick *et al.* 2015)

Other questions were investigated, including if there was a trend over the three years when just comparing student responses at the start of Year 1 for the three years of data and separately comparing student responses at the end of Year 4 for the three years of data. The purpose of this was to check for general trends in student perception over the three years that would not be attributed to the strategic approach of incorporating sustainable development in the four-year curriculum. No trends were observed when comparing responses from Year 1 students through AY2016-17, 2017-18, and 2018-19. Similarly, no trends were observed when comparing responses from Year 4 students through AY2016-17, 2017-18, and 2018-19. Upon completion of Year 4 students at the end of AY2019-2020, results can be compared longitudinally for a single cohort from the start of Year 1 to the end of Year 4.

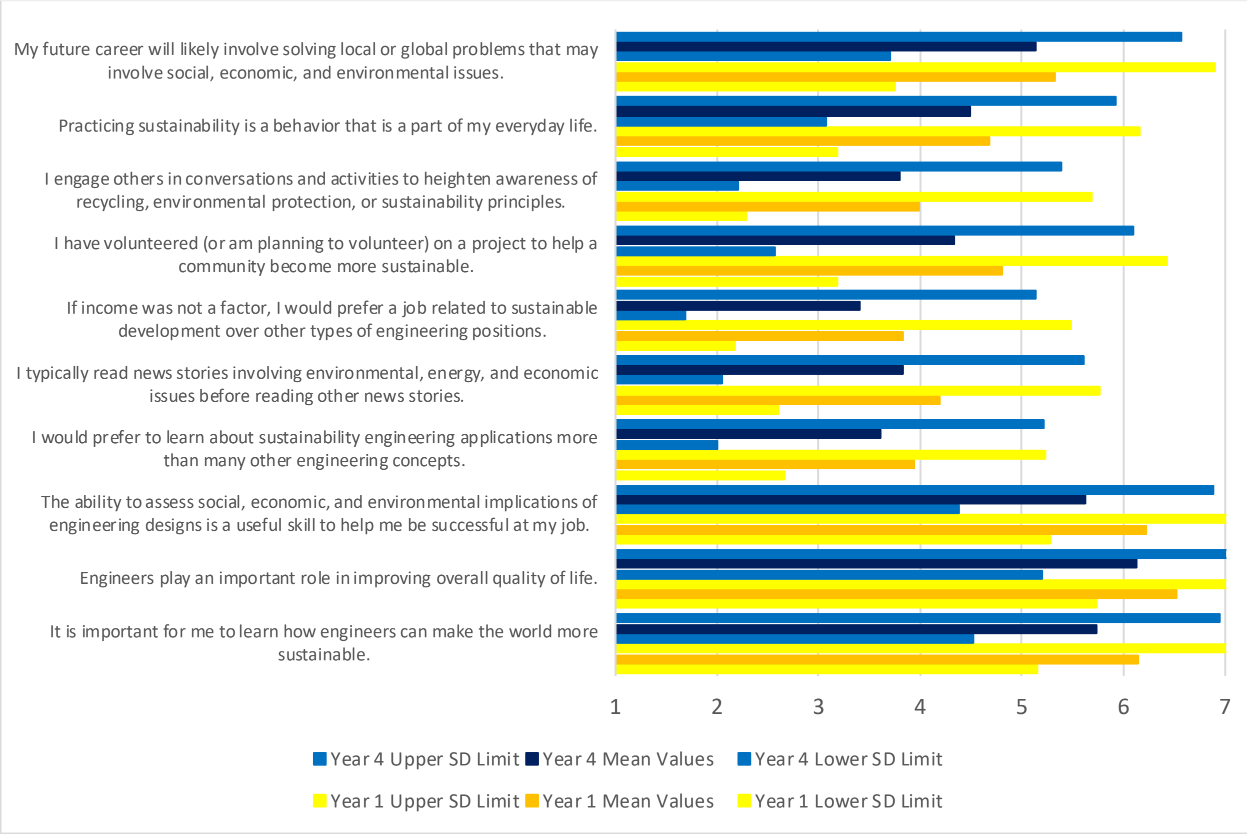

Figure 2: Ratings on a scale of 1 (strongly disagree) to 7 (strongly agree) of value perceived in sustainability and sustainable design from AY2016-17, 2017-18, and 2018-19; SD = standard deviation; Year 1 n=71, Year 4 n=83 (survey questions from McCormick *et al*. 2015)

4 Conclusion

Through the threads of learning approach, learning occurs not within a single course but across several courses spanning the four-year curriculum. This allows faculty to incorporate sustainability in the context of technical designs, which provides students a more continuous exposure to understanding impacts of their design decisions and creating value in the broader, holistic perspective of engineering projects. By not solely addressing sustainable design in a single, self-contained course, students also experience applications of sustainable design integrated into several courses to emphasize the perspective that addressing sustainability is just part of the engineering design process and not an ancillary topic.

Although perception of importance or value in sustainability did not increase, the confidence in ability to achieve tasks related to assessing and incorporating sustainable design in engineering projects increased from the start to the completion of the four-year civil and environmental engineering undergraduate curriculum. This study showed that cognitive development did not directly lead to affective development, in general. Future studies will longitudinally track a single cohort of students to compare responses at the beginning and end of their undergraduate academic career to yield more deterministic results of following the same group of individuals, as opposed to investigating different sample sets of students from the same population.

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