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Piloting a framework to evaluate and guide student understanding of global, socio-cultural, environmental and economic design factors

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Abstract

Several previous studies have highlighted the sociotechnical nature of engineering practice while simultaneously recognizing the gap in student learning of sociotechnical factors in undergraduate engineering education. Furthermore, students struggle to see the relevance of understanding and engaging with five key design factors: global, social, cultural, economic and environmental as assessed by competency frameworks at the university and accreditation levels. This study piloted a series of in-class engagement activities in a water and wastewater design class to be used in Civil and Environmental engineering courses to enhance student understanding and learning of the five design factors. Activities included a pre-activity and post-activity survey of student knowledge of the design factors, confidence level with a design project solution, and appropriateness of the design project. Additional activities included individual and group analyses of a design scenario, guided activities designed to simulate client engagement in practice, and peer-review sessions where students gave each other feedback on their designs. Results indicate that the designed activities help students move from a high-level understanding of each design factor to a more nuanced understanding of how to apply the design factors to water and wastewater projects specifically. Students showed an increase in confidence in their design from a technical perspective but increases in confidence are confounded by students' newfound awareness of "appropriateness". The pilot data and activities in this study generated sufficient data to evaluate the research questions proposed by this study and require revision and refinement in other courses to assess their broader applicability in the Civil and Environmental engineering curriculum.

Key words: sociotechnical literacy, competency-gap engineering education, sociocultural approaches, comprehensive design

Highlights:

- Guided activities related to global, cultural, social, economic and environmental factors helped students move from a basic understanding of these design factors to understanding the importance of considering system-specific design factors
- Student confidence in their engineering designs increased after completing the class activities, with a noticeable awareness of "appropriateness of design" evident from student feedback
- Students appreciate feedback from the instructor on the group design project, particularly on the appropriateness of their design and cite the need for early and frequent feedback

Introduction

Once engineering students complete an undergraduate engineering degree, they have theoretically achieved the competencies necessary to obtain professional jobs in industry. However, evidence from literature and professional engineers working in industry have noted that while students possess the technical competencies to perform their jobs well, students lack an understanding of real-world design factors that play a critical role in the design process [1], [2], [3], [4], [5]. Specifically, students who become new professionals often need coaching and experience to understand the project and community-specific characteristics of each design, leading to miscommunication and the potential for the design of inappropriate solutions for a client in early years [1], [6], [7]. Professionals have observed that students are able to apply equations, use computer programs and correctly calculate values, but are unable to articulate design factors that influence a design and are influenced by a design [3], [8].

Similarly, at the University of Nebraska-Lincoln (UNL), during an evaluation of student outcomes for ABET review, faculty members noted a decrease in proficiency with student outcome 2, specifically related to global, cultural, social, environmental and economic factors that are influenced by design and influence a design (hereafter referred to as the "5 design factors"). This is not a unique problem at UNL; indeed, past studies have found that students learning of these design factors is superficial at best, demonstrating comprehension, but not an ability to critically evaluate and interpret how these factors are applied in the engineering field [9], [8]. Furthermore, while faculty members in Civil and Environmental Engineering programs across the United States are experts in their field, many instructors did not work in the engineering industry prior to becoming an academic [10], [11]. As a result, there is a gap in instructor knowledge about how to best teach these design factors in a way that enriches student comprehension and provides students with the necessary background to apply concepts in a professional setting. The challenge of designing a course that addresses each design factor with depth and breadth is a large one, made more difficult by the fact that there are subdisciplines within Civil and Environmental engineering programs (transportation, geotechnical, structures, water resource engineering, etc.). As a result, there is a clear need to consider a holistic approach faculty can use to teach students these factors within design courses at the undergraduate level.

Students also bring different life experiences and identities to each course taken in a curriculum [12], [13]. As a result, the evaluation of student learning is confounded by the presence of students with industry and intern experience (whether in engineering or not), making it difficult for instructors to determine the baseline knowledge of students. Students without prior experience with any of the five design factors may feel intimidated by, for example, thinking globally about how the design of water treatment facility in rural Nebraska is influenced by global factors and in turn has impacts on other countries across the globe. Subsequently, developing better methods to track and understand student comprehension of these five design factors is a key step in determining how to best improve teaching pedagogy related to these factors.

The challenge of teaching and evaluating these critical design factors is a multi-faceted problem. First, it is difficult to teach each of these design concepts without a clear definition of what each factor encompasses. For example, where do instructors and students draw the line to distinguish cultural from social factors when many textbooks and previously developed materials use the term socio-cultural to acknowledge the difficulty of differentiating the two? Students struggle to identify these factors when the factors have not been first clearly defined by an instructor. Furthermore, even if an instructor has extensive real-world knowledge about their field, they may not have concrete examples of each factor that they can use to help teach students these concepts. As a result, there is the dual challenge of not only framing and defining each factor, but also conveying each factor to students in a comprehensible way that allows students to identify and articulate specific design factors on their own. Indeed, in the larger engineering education literature, discussions and investigations are still being conducted to determine how to define “non-technical” factors that encompass social and cultural implications of a design, with terms like “sociotechnical” being used to define this area of study [14].

There are two gaps this research aims to address. First, from the student perspective, there is a need to understand baseline student knowledge about each of these design factors, what activities promote student understanding and what activities provide students with the skills to articulate and apply concepts without instructor guidance. Students need guidance to learn about each design factors, some of which are very difficult to articulate, especially in a very technically oriented industry such as engineering. In addition, students may understand at a high-level what design factors may be associated with engineering in general but cannot identify and explain these design factors in relation to specific engineering projects post-graduation. Second, from the instructor perspective, there is a need to develop strategies and activities that instructors can apply to their classroom teaching to not only better convey concepts, but to build student confidence in their ability to identify design factors without guidance. Not all instructors have extensive experience with each of the design factors, even if they are a specialist in one area, or have a general knowledge of each. Having a structure available will help instructors develop content that achieves student outcomes related to each of the design factors, particularly in design courses where learning to apply these factors is critical to student’s future professional success.

At the University of Nebraska-Lincoln, recent data collected for Accreditation Board for Engineering and Technology (ABET) assessments revealed that the Civil and Environmental Engineering department has room for improvement related to student outcome 2 (SO2). Specifically, improvements need to be made in the delivery, assessment and student learning outcomes related to five key factors that influence engineering design: global, cultural, social, environmental and economic. Throughout the rest of this paper, these factors will be referred to commonly as “design factors”. Through an evaluation of three years worth of ABET data, the department determined that: (1) each professor is developing and implementing materials separately, (2) each professor is assessing proficiency with this student outcome differently leading to a concern with inter-rater reliability and (3) it is unclear if students can identify each of these design factors without the aid of a professor. Anecdotal evidence suggestions across both professors and students, that it is unclear what the difference between a “social” and “cultural” factor is, with each course in the curriculum potentially defining a factor in a different way.

Therefore, this pilot study had the following objectives: (1) design a structure to evaluate student learning of the five key design factors from both the student and professor perspective, (2) implement and review a set of in-class activities designed to teach students about the five key design factors in a pilot course and (3) provide recommendations based on the pilot course data for an expansion of this study at the departmental level. The study aimed to explore the following research questions:

> (1) How do structured definitions of each design factor help to improve student’s ability to identify design factors?

(2) How do structured activities (both individual and group-based) give students the necessary information to generate specific examples of each design factor in relation to both (a) general engineering projects and in relation to (b) a discipline-specific design project?

Recommendations presented as part of objective three will provide insight to explore the following broader research questions to be answered in future work with a larger sample set:

1. How does a common definition of each factor improve instructor's ability to teach these different design factors?
2. How do pre- and post-activities help an instructor assess student proficiency in relationship to the ABET SO2?
3. How does having a clear structure/ possible suite of activities improve instructor comfort teaching these design factors?

Methodology

In Spring 2023, a series of individual and group activities were completed in the design elective course "Environmental Engineering Process Design" (CIVE 420) to answer the research questions posed in the introduction. CIVE 420 covers basic water and wastewater treatment design, focusing on engineering calculations and design of treatment unit processes. Data were collected from 14 students, seven located on the Lincoln campus and seven located on the Omaha campus. The class consisted of 12 seniors and 2 juniors, with 10 declared Civil engineering majors and 4 declared environmental engineering majors. Table 1 provides the breakdown of students across each campus. The methods that follow are organized by which research question the methods attempted to address.

Table 1: Student breakdown by campus, major and year.

Characteristic		**Campus**	
		Omaha	**Lincoln**
Major	Civil Engineering	6	4
	Environmental Engineering	1	3
Year of Study	Junior	1	1
	Senior	6	6

Determining baseline student knowledge

The sample of students included in this exploration was comprised of two majors and represented both juniors and seniors. As a result, it was necessary to understand baseline student knowledge about the five design factors in relation to both the factors in general and to water and wastewater design specifically. Three components were used to determine baseline student knowledge: a six-question pre-activity survey, a pre-lecture video students watched prior to class, and an individual analysis of a design scenario (provided in the SI) prior to sharing ideas with fellow students. The pre-activity survey was used to allow students to communicate to the instructor whether students had seen these design factors in previous classes in the Civil and Environmental engineering curriculum and how comfortable they felt with the design factors specifically in reference to the CIVE 420 course. A full list of questions asked in the pre-activity survey is presented in the Supplemental Information (SI).

Prior to in-class activities, students were asked to watch a pre-lecture video about the five design factors. Pre-lecture videos were an integrated component of the course (taught as a flipped classroom), and students are expected to know key background information about a topic prior to class activities. The pre-lecture video defined each of the five design factors and presented a case study example. The video was hosted on a public viewing platform; as a result, while the number of views can be verified, it was not possible to determine whether each student watched the video. A broad definition of each design factor was provided to help determine if there are specific design factors students have more difficulty understanding and applying.

Finally, at the beginning of class, students were asked to individually create a list of design factors specifically related to a provided design scenario for drinking water and wastewater design (available in the SI). Students were given ten minutes to ideate factors either on paper or a computer program and submitted their lists to the instructor via the Canvas learning information management platform. The instructor then compared the student generated lists to the case study example given in the pre-lecture to determine whether the student performed "as expected", generated "less than expected" or "more than expected". A student who performed "as expected" generated a list of factors similar to what was given in the pre-lecture case study with possibly one additional factor or unique idea. A student who performed well and generated "more than expected" listed factors or ideas above and beyond the case study presented in the pre-lecture. A student who generated "less than expected" was unable to identify factors consistently or did not identify at least one factor in two different categories or showed little to no effort or preparation for class.

The pre-survey results (questions 1 and 2) and the instructor's assessment were assessed using a decision tree (SI) which assigned point values to specific answers. A total number of points was assigned to each student, with the number of points then being translated to one of the four proficiency levels: novice, apprentice, proficient or exemplary. For the purposes of baseline assessment, exemplary was excluded from the analysis to account for the fact that students needed to be able to specifically articulate factors related to a specific design scenario, an item that would be assessed in the post-activity components. The proficiency levels were defined as the following in accordance with the ABET definitions provided for student outcome two (more details in SI Table S1):

- **Novice** - Fails to analyze impacts on global, cultural, societal, economic, and environmental factors
- **Apprentice** - Analysis of impacts on global, cultural, societal, economic, and environmental factors is incomplete and/or does not address all five aspects (i.e., global, cultural, societal, economic, and environmental factors)
- **Proficient** - Adequately analyzes impacts on global, cultural, societal, economic, and environmental factors

- **Exemplary** - Comprehensively and adequately analyzes impacts on global, cultural, societal, economic, and environmental factors

Once an initial proficiency level was assigned, students then progressed through the following outlined activities designed to increase their ability to identify and articulate specific design factors.

Student *exploration* of design factors

The first activities students participated in during class time were a brief 15 minute lecture on an example case, the introduction of the design scenario (presented in the SI), a Group Analysis #1 of factors related to the design scenario, and then a session where the instructor acted as a "community member" in a "town hall" style activity where students could ask the "community" questions to obtain more information. These activities were designed to get students exploring the five design factors both with the instructor and with their peers. Based on student responses to Individual Analysis #1, it was clear that not all students completed the pre-lecture activities; as a result, the mini-lecture at the start of the class was designed to give students time to familiarize themselves with the concepts. The lecture at the start of the class reviewed the case study presented in the pre-lecture for students but did not redefine each of the design factors.

The design scenario used a small, rural community in Nebraska as an example. The design scenario described the characteristics of a fictional community and presented the need for a new drinking water system or a wastewater system, only presenting high-level details to encourage the students to ask questions. Students were provided the design scenario prior to class. After reviewing the design scenario, students were given 15-20 minutes with classmates to generate a list of design factors related specifically to the design scenario. Four groups were formed of 3-4 students and students either used their computers or posters to record information from the group analysis. Students then submitted their Group Analysis #1 to Canvas by either submitting their online document or taking a picture of their posters. Finally, students engaged in a "town hall" with the professor acting as the client from the "community". Prior to class, the professor prepared additional information about the community to have ready for student questions. Students were given 15 minutes to ask the community questions and directed to take notes for future activities in subsequent class lectures.

Student *synthesis* of design factors

At the start of the second class dedicated to this activity, students were given the opportunity to generate additional questions for the "community" with their groups from the previous class and then ask the clients those questions. As part of this activity, after the students finished asking the "client" questions, the class worked together with the professor to generate additional questions that may have been beneficial to ask the client. In addition to this activity, students worked with the instructor to choose a specific design factor and generate a more detailed list of design factors to help students start to understand the importance of being specific when considering design factors. Students selected "environmental" and "cultural" as their focus and the professor worked with students for 20-25 minutes to work through how to find specific factors. For example, instead of using "cultural preferences" as a cultural factor, the instructor prompted the students to think deeper, generating ideas such as "making sure project sites do not interfere with important landmarks and heritage sites" and "honoring cultural views of the importance and significance of water" in the process of selecting an appropriate technology.

After gathering additional information from the client and from online resources, if necessary, students worked in the same groups to complete Group Analysis #2. Group Analysis #2 consisted of choosing either a drinking water or wastewater system to focus on, and then presenting an initial proposed solution to the client in the form of three PowerPoint slides submitted to Canvas. Students were asked to have at least three slides in their submission to this activity: a slide showing a basic flow diagram of their proposed solution, a slide with a paragraph describing the design and design factors that were considered and a slide containing a chart or table of the design factors that need to be considered in the design of the student's solution.

Student *application* of design factors

Finally, on the third day of activities, students turned their focus from a hypothetical design scenario to their own proposed solutions for their semester group project in an attempt to get students thinking about the *application* of design factors to a real-world scenario. Over the course of the semester, students worked with a non-governmental organization (NGO) to design initial drinking water and wastewater systems for very small, underserved communities (full description of project in SI). Students were provided water quality and wastewater quality data for their community to use to design an appropriate solution. Students had completed an initial design for both drinking water and wastewater treatment and were finishing their final reports and presentations the following week in class. One of the activities students participated in was a peer review of their design by students and the professor to help students understand the appropriateness of their design and hopefully to increase student confidence in their design. The peer review activity was structured as follows:

- Students used their design groups, 2 groups on each campus and reviewed the other group on the same campus. For the purposes of explanation, Group A reviewed Group B's design and vice versa.
- First, Group A reviewed the water quality and wastewater data from Group B and vice versa and generated a list of key concerns Group A thought Group B's treatment solution should address.
- Then, Group B presented their solution to Group A and Group A asked questions based on their newfound knowledge of water and wastewater quality. The groups then switched roles.
- Next, the professor and group members asked questions about the design, with the professor guiding students to think about each of the five design factors.

After the peer review, students were asked to share some of their findings with the class and reflect on the appropriateness of their design. Students were then given time to complete Individual Analysis #2, which asked students to specifically examine their community for their group project and provide a comprehensive list of all of the possible design factors that were of importance to their design. Students then submitted their Individual Analysis #2 to Canvas as the last in-class activity.

Determining post-activity student learning/understanding

Finally, students were asked to complete the post-activity survey and submit their answers to Canvas. The post-activity survey had several of the same questions as the pre-activity survey, in an attempt to determine if students gained knowledge about the design factors through the in-class activities. Post-activity survey questions are provided in the supplemental information. Using the post-activity survey and Individual Analysis #2, the instructor then repeated the same exercise as described for pre-activity knowledge to determine the proficiency level of students after class activities. The flow diagram of this decision-making process is provided in the supplemental information. Figure 1 summarizes the activities completed prior to, during and after class with the intended outputs on the left side of the figure.

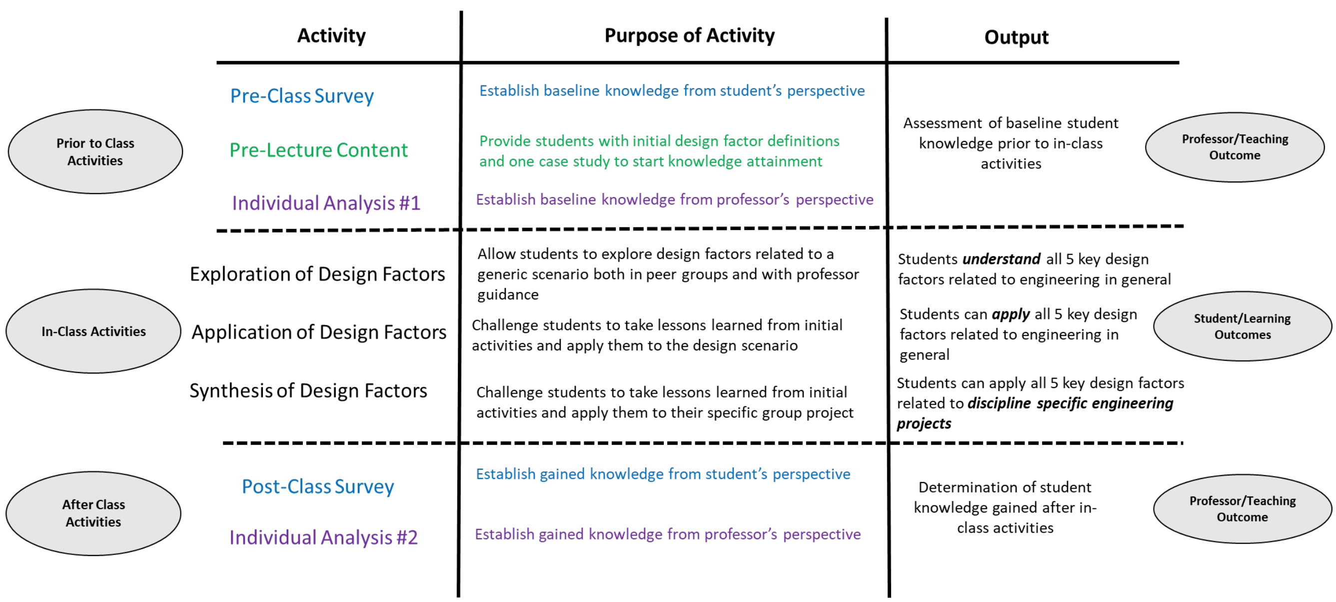

Figure 1: Methods used to assess student learning of five key design factors

Results

Results in this paper are presented in the following way: (1) student knowledge prior to in-class activities, (2) student knowledge gained after in-class activities and (3) student proficiency levels both before and after in-class activities.

Student knowledge prior to in-class activities

Results from the determination of student baseline knowledge demonstrated that the majority of students felt they understood the five key design factors prior to class (Figure 2A), but in a general capacity. Comments from students identified three different classes where they had prior exposure to design factors: one class that is a senior-level civil engineering elective, one that class that is a senior-level required environmental engineering major core requirement, and one class that is a senior-level design course currently required for both majors. Because almost all students were seniors, it was therefore unsurprising the majority of students have had prior exposure to the design factors at some point in their academic career, although it is notable that exposure is not happening in formative classes prior to senior-level courses. Students felt more comfortable with the five key design factors in related to water and wastewater treatment specifically prior to activities (Figure 2B), most likely as a result of how this class was structured to include these design factors throughout the course.

In addition, student responses to the Individual Analysis #1 activity showed students have a hypothetical, high-level understanding of all the design factors. For example, under either the global or environmental factor, most students identified "global warming" as a concern. Based on the instructor evaluation of Individual Analysis #1, 42% performed as expected based on the pre-lecture content supplied, 29% performed better than expected and 29% performed less than expected. Students who indicated design factors were familiar in the survey tended to perform as expected or better than expected. Combined with the results presented in Figure 2A and 2B, prior to class, most students had verifiable high-level understanding of all design factors.

Of the five design factors, students were most likely to identify economic and environmental factors influencing engineering designs. Students were likely to note economic concerns such as "budget" or "funding" but did not elaborate on exactly how these factors have an influence on engineering design projects. In addition, other economic factors included "small systems financial capabilities" and "system operation and maintenance costs", showing that students do have at least some prior knowledge from other classes or from this class that these are valid economic concerns. Environmental factors commonly identified by students included the following: weather impacts from a variety of events, "global warming", "ecosystem preservation" and concerns about disposal of wastewater to receiving waters. There is some evidence that students are starting to think about these two example factors in terms of water and wastewater treatment prior to activities, particularly through the identification of wastewater disposal concerns and small systems economics, but only a minority of the students in class had begun to think through these specific examples prior to class activities.

Finally, prior to class, Figure 2C and 2D support the idea that while students can *identify* general concepts related to each design factor, they express uncertainty related to the *application* of these concepts to a specific design scenario. In the context of this class, students were participating in a group project related to designing drinking water and wastewater systems for small, rural communities and did not have regular contact with their clients. As a result, in student comments in the pre-survey some students indicated that a lack of confidence was related to the structure and constraints of the project; one student explicitly states that if there had been more client interactions, they would have selected "Somewhat confident" instead of "Not confident". In addition, initially students expressed uncertainty about the appropriateness of their designs. Context from student comments shows this was in part due to the fact students were learning general design calculations for generic water and wastewater systems at the same time they were completing the project. Other student comments reveal the need to consider how design factors are different in small systems context.

Student knowledge after in-class activities

Figure 2A and 2B support the hypothesis that the in-class, facilitated activities would improve student understanding of the design factors, both generally and related specifically to the drinking water and wastewater industry. While prior to class some students selected "Not well" for understanding of design factors, after the activities, none of the students selected "Not well", with all students selecting "Very Well" or "Well" for both engineering design in general (Figure 2A) and for drinking water and wastewater specifically (Figure 2B). After class, the percentage of students who felt they understood design factors "very well" increased from 7% to 55% for general engineering projects and from 36% to 64% for drinking water and wastewater projects specifically.

Student responses to Individual Analysis #2 showed that not only could students articulate factors for all five of the design factors, but could also do so with greater specificity. For example, instead of students identifying "global warming" as a design factor, student responses included variations on the following: "increased incidence of storms due to global warming impact infrastructure resiliency" and "changes in climate could impact water quality in source waters." These more detailed responses show that the guided synthesis in-class activities helped students to contextualize the design factors to a specific case study in greater detail than prior to class. Based on instructor evaluation of Individual Analysis #2, students meeting expectations changed from 42 % to 33 % of the class (different denominators, 3 students did not complete the post-class survey) and students exceeding expectations increased from 29% to 44%.

After class activities, almost all students were able to articulate at least 2 design factors within each category as opposed to the heavy emphasis on environmental and economic factors seen in Individual Analysis #1. As part of the class activities, the professor led the students through a guided activity designed to find specifically how one of the design factors could influence engineering designs. The students selected "cultural" factors for this exercise, and it is clear from student responses to Individual Analysis #2 that students began to internalize the process of becoming more specific with how design factors influence engineering projects.

Finally, Figure 2C shows increased student confidence in their group project design solutions with students feeling "Somewhat confident" decreasing from 64% to 27 %. In addition, in the post-activity survey, 18% of students felt "Very confident" in their designs. However, student comments reveal that there are confounding factors as to why the decrease in "somewhat confident" was relatively small. Student comments indicated that examining the five design factors actually showed them some gaps they did not initially consider in their initial group project designs. As a result, while they did not necessarily feel more confident in their designs, they did express an understanding of whether their designs were appropriate for the community they were designing for. Figure 2D shows that 21% of students were "Not sure" or thought their design was "Not appropriate" prior to class activities; this figure decreased to 0% after class activities. Students indicating their design was "Appropriate" or "Very Appropriate" increased from 42% to 73% after class activities. As a result, these pilot data suggest that the peer review activity and guided sessions helped students understand if their designs fit into the context of the scenario they were designing for, including considerations for the five design factors.

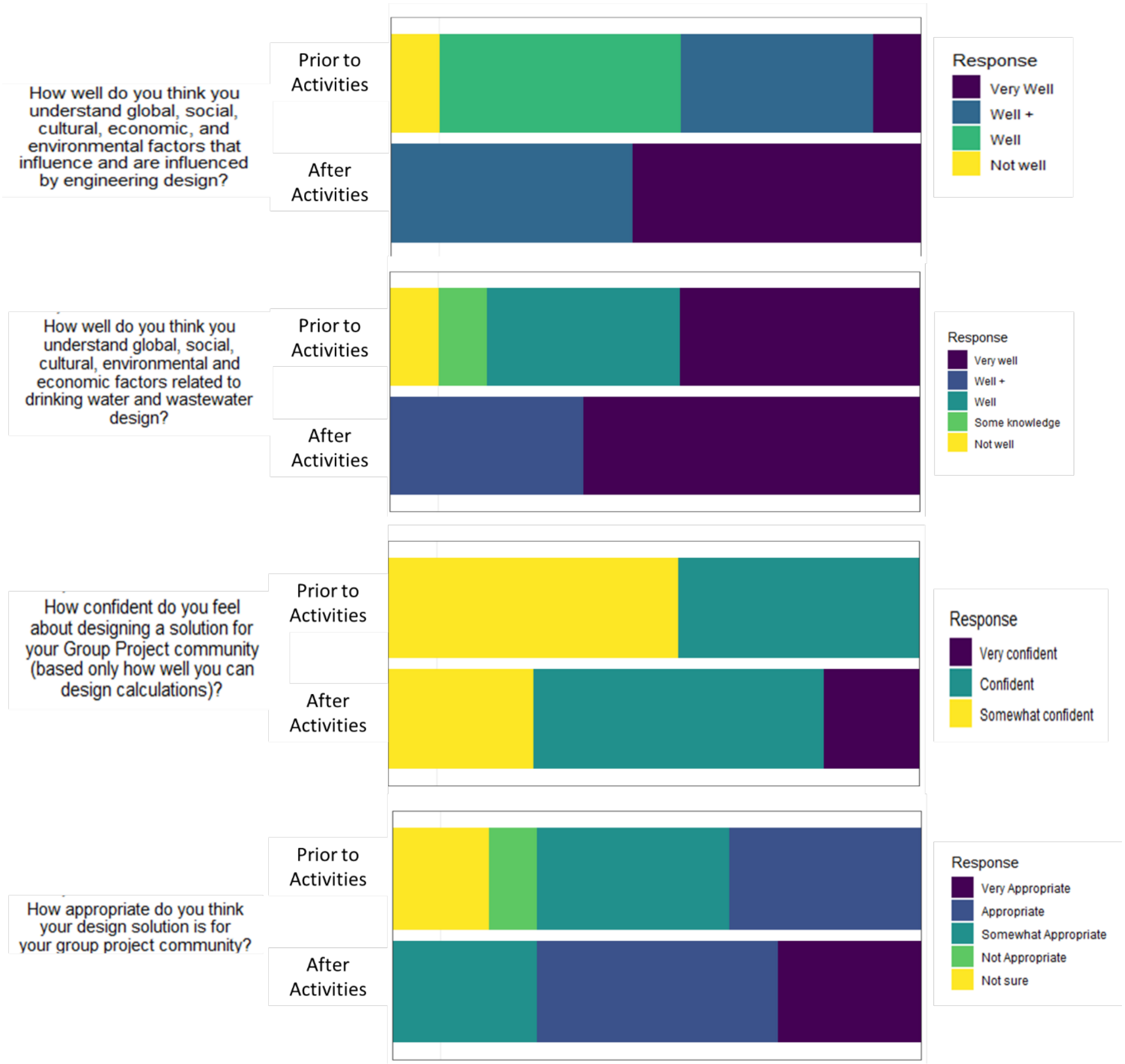

Figure 2: Student responses to pre-activity survey and post-activity survey

Changes in student proficiency levels

The evaluation of student proficiency (using the ABET proficiency descriptors) showed that in-class activities increased student proficiency for five students, with the remaining nine students staying at the same proficiency level (three of which were due to incomplete post-activity items). Initially, one student was assigned “Novice”, six students were assigned “Apprentice” and seven students were assigned “Proficient”. Of the proficient students, six were seniors who had at least some exposure to the design factors in other, previous classes. After class activities, no students were assigned “Novice”, three students were assigned “Apprentice”, eight students were assigned “Proficient”, and two students were assigned “Exemplary” (Figure 3). Increases in proficiency were seen from novice to proficient, apprentice to proficient, apprentice to exemplary, and proficient to exemplary with no students decreasing in proficiency after the class activities. Information showing how each proficiency level was determined both prior to and after class activities is presented in the Supplemental Information.

At the University of Nebraska-Lincoln, CIVE 420 is considered a summative elective course for ABET evaluation standards. As such, analysis for ABET at UNL considered the percent of students achieving levels of “proficient” and “exemplary” in their continuous improvement process. Using this information, prior to class, only 50% of students were considered “proficient” or “exemplary”. However, after class 79% (11 out of 14) of students of students were considered "proficient” or “exemplary” with the remaining three students remaining at “apprentice” because no post-activity data was submitted. While these proficiency levels are subjective and only represent data from only one course with a small sample size, there is at least some evidence that the in-class activities were effective at increasing student awareness, if not full understanding of the design factors.

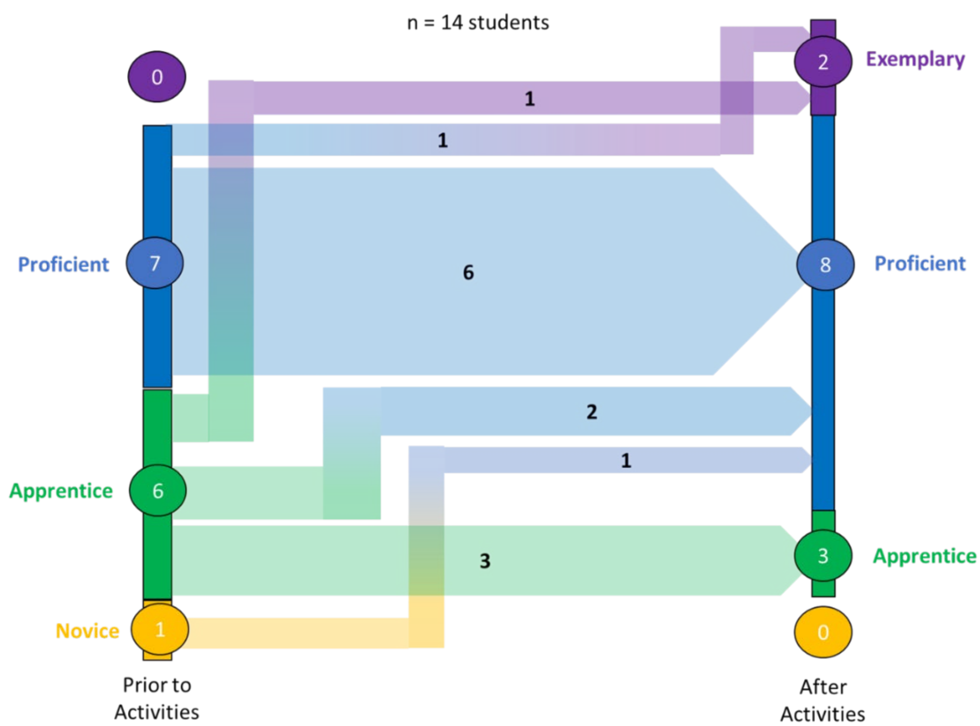

Figure 3: Improvement in student attainment of ABET levels pre-activity and post-activity

Discussion

One of the important results observed in this pilot study was student’s transition from understanding design concepts in general, to being able to more specifically expand on an individual design factor and to apply that specificity to a real-world problem. While both the design scenario and group project did not have the extensive real-world client engagement necessary to truly identify project-specific design factors, there was nonetheless an observed increase in the specificity of student answers from pre-class activities to post-class activities.

This is critical not only from the perspective of evaluating ABET outcomes, but also from the perspective of developing career-ready engineers. ABET rubrics at UNL for the student outcome related to these design factors specify students can "generate and analyze possible design solutions", "consider the impact of design" on the design factors identified in this study and "select an acceptable design solution". Results from this study show that 50% (proficient prior to class) of students can at least identify factors prior to in-class activities, but the application, analyzation and appropriateness of designs improves to 64% (proficient or exemplary after class) after class activities are completed. In engineering practice, students will need to be able to *apply* these design factors as professional engineers [3]. The activities piloted in this study show that for the sample size available, there is an increase in student's ability to apply their knowledge of design factors to specific projects with greater specificity than prior to class.

Engineering students must be able to understand context and project-specific design details when working in the industry to ensure the successful implementation of their engineering solutions [15]. These design details provide vital information about the specific requirements and constraints of a project, enabling engineers to fully comprehend the scope and objectives of their work. By understanding the project-specific design details, engineers can effectively analyze the problem, identify potential challenges, and develop optimized solutions. It helps in minimizing errors, enhancing the efficiency of the design process, and ensuring the final product meets the desired specifications. Hence, engineering students who master project-specific design details will be well-prepared to navigate the intricacies of the industry and contribute to the successful completion of projects. Integrating discipline-specific activities within the engineering classroom may provide opportunities for students to practice implementing project-specific design details before entering industry, creating students that are better prepared for the demands of real-world engineering work and taking critical steps toward closing the competency gap.

This study also observed an increase in student confidence in their engineering design, but only a marginal increase. Confidence in student designs and the appropriateness of student designs are linked, but there was an increasing observed relationship between confidence and appropriateness. Based on student comments, students felt more confident in their ability to identify design factors and to complete a technical design of a water or wastewater system after class activities but expressed awareness that the non-technical factors such as social and cultural implications of a design made them question the appropriateness of their proposed design. Comments also support the idea that students thought their design choices had the technical characteristics to be considered an appropriate water/wastewater design but did not think the solution was appropriate based on the non-technical factors such as social and cultural. While additional studies would be needed to tease out the nuances between confidence and appropriateness, we can at a minimum note that students become more aware of the concept of "appropriateness" through the activities designed for this study. Notably, during student final presentations of their group project design (not included in this study), unprompted, one group completed a "treatment retrospective" as part of their presentation to the client. The team reviewed some of the factors they did not consider during their initial design and presented ideas on how to resolve these factors to the client. This unprompted addition to the group project provides additional evidence that student awareness of "appropriateness" increased in relation to water and wastewater treatment specifically, showing students are interested in and aware of the important of the key design factors in their design.

Student comments revealed student eagerness to receive feedback and guidance on their group project designs, not only earlier in the semester from their peers, but from the client and professor as well. Students exhibited a desire to apply design calculations and concepts appropriately to real-world projects, citing these in-class activities as a very useful outcome for the class as a whole. One student remarked that this was one of the only classes where design factors were *explicitly* discussed, applied and analyzed as opposed to *implicitly* discussing factors during lectures focused on different topics. Thus, one of the important outcomes of this study is the importance of allowing students time to apply design factors to a scenario as opposed to lecturing only. Applying design factors to a specific project and specific aspect of Civil and Environmental engineering (water and wastewater treatment) gave students a better understanding of design factors related to a specific field (Figure 2B) while also increasing students understanding of the design factors overall (Figure 2A), as shown by the increase in the number of students reporting "very well" in the post-activity survey. While this study cannot conclusively say that the peer-review activities were the reason student proficiency increased, previous studies suggest that active learning style activities and peer-review activities in general do increase student engagement with and understanding of class material [16]. Applying and studying peer-review techniques for activities related to the design factors discussed in this study can be studied further to improve the baseline activities suggested in this study.

The peer review session and feedback were also linked to student's answers about "confidence" and "appropriateness". There were two sections of this class, one located in Omaha, and one located in Lincoln, with the instructor traveling between locations each week to ensure in-person reactions with both sections. The peer review session was completed in person with the Lincoln students; results indicate that students in Lincoln felt more confident post-activities than Omaha in general, possibly due in part to in-person interactions with these students. There was more dialogue between the Lincoln section and Omaha section due to the distance learning interaction present on the day of the dialogue, a factor which may have influenced the "confidence" answers to the post-survey questions. In addition, peer review sessions generated alternative solutions that a group may not have thought of initially. A previous study from quantum engineering saw a similar improvement in paper writing as a result of peer review activities, showing there are examples of beneficial peer-review activities generating positive impacts in engineering education[17] and more broadly in computer engineering as well [18]. The peer-review session asked students to give each other feedback, resulting in students thinking of new, possibly more appropriate solutions they had not considered. Awareness of alternative solutions is likely a contributing factor to student's uncertainty surrounding the appropriateness of their water and wastewater group project design. Overall, we noted that students are confident in their technical skills to design a water and wastewater solution but are unsure of the appropriateness of their design from a non-technical perspective.

Conclusion

The activities developed and piloted in this study show promise as standard activities that can be used to teach students about the five design factors examined in this study: global, social, cultural, economic and environmental. Students showed an increase in proficiency with all five factors overall, with a greater increase in discipline specific (water treatment) projects. In addition, an increase in confidence was observed related to the class design project, although it was noted that while student comments support an increased understanding of design appropriateness, they would require additional guidance and activities to increase their confidence with the appropriateness of their design. We also observed an increase in the ability of students to identify specific design factors, moving from high level factors sch as "global warming" to more detailed system-specific factors such as "increasing climatic events will have an impact on infrastructure resiliency". We noted that students have an appetite for guidance and peer review from not only the course instructor but also from real world clients that will be important to incorporate in expansions of the work completed in this study. Finally, adapting and applying these activities to other discipline specific Civil and Environmental engineering courses is a logical next step to validate the pilot results presented in this study in the large context of Civil and Environmental engineering curriculum development related to the five key design factors.

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References

[1] A. M. Boelt, A. Kolmos, and J. E. Holgaard, "Literature review of students' perceptions of generic competence development in problem-based learning in engineering education," *Eur. J. Eng. Educ.*, vol. 47, no. 6, pp. 1399–1420, Nov. 2022, doi: 10.1080/03043797.2022.2074819.

[2] J. Buckley, J. Trevelyan, and C. Winberg, "Perspectives on engineering education from the world of practice," *Eur. J. Eng. Educ.*, vol. 47, no. 1, pp. 1–7, Jan. 2022, doi: 10.1080/03043797.2021.2000694.

[3] C. K. Y. Chan and L. Y. Y. Luk, "Academics' beliefs towards holistic competency development and assessment: A case study in engineering education," *Stud. Educ. Eval.*, vol. 72, p. 101102, Mar. 2022, doi: 10.1016/j.stueduc.2021.101102.

[4] D. S. Claussen, S. F. S. Unviersity, and D. J. Y. Tsai, "Exploring the Nexus Between Students' Perceptions of Sociotechnical Thinking and Construction of their Engineering Identities," 2021.

[5] B. Williams, J. Figueiredo, and J. Trevelyan, *Engineering Practice in a Global Context: Understanding the Technical and the Social*. Taylor & Francis, 2013. [Online]. Available: https://books.google.com/books?id=SVpmAQAAQBAJ

[6] A. Kolmos and E. de Graaff, "Problem-Based and Project-Based Learning in Engineering Education: Merging Models," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds., 1st ed.Cambridge University Press, 2014, pp. 141–160. doi: 10.1017/CBO9781139013451.012.

[7] S. A. Male, M. B. Bush, and E. S. Chapman, "Perceptions of Competency Deficiencies in Engineering Graduates," *Australas. J. Eng. Educ.*, vol. 16, no. 1, pp. 55–68, Jan. 2010, doi: 10.1080/22054952.2010.11464039.
[8] H. J. Passow, "Which ABET Competencies Do Engineering Graduates Find Most Important in their Work?," *J. Eng. Educ.*, vol. 101, no. 1, pp. 95–118, Jan. 2012, doi: 10.1002/j.2168-9830.2012.tb00043.x.
[9] R. Malhotra, M. Massoudi, and R. Jindal, "Shifting from traditional engineering education towards competency-based approach: The most recommended approach-review," *Educ. Inf. Technol.*, vol. 28, no. 7, pp. 9081–9111, Jul. 2023, doi: 10.1007/s10639-022-11568-6.
[10] S. Sheppard, A. Colby, K. Macatangay, and W. Sullivan, "What is Engineering Practice?".
[11] R. B. Freeman and H. Salzman, *U.S. Engineering in a Global Economy*. University of Chicago Press, 2018. doi: 10.7208/chicago/9780226468471.001.0001.
[12] R. Stevens, K. O'Connor, and L. Garrison, "Engineering Student Identities And The Navigation Of The Undergraduate Curriculum," in *2005 Annual Conference Proceedings*, Portland, Oregon: ASEE Conferences, Jun. 2005, p. 10.558.1-10.558.8. doi: 10.18260/1-2--14754.
[13] M. H. Hwang, E. Trueblood, and S. A. Claussen, "Engineering Identity, Perceptions of Sociotechnical Education, and Views of Engineering Practice in Undergraduate Students," in *2022 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden: IEEE, Oct. 2022, pp. 1–10. doi: 10.1109/FIE56618.2022.9962377.
[14] K. Johnson, J. Leydens, B. Moskal, and S. Kianbakht, "Gear switching: From 'technical vs. social' to 'sociotechnical' in an introductory control systems course," in *2016 American Control Conference (ACC)*, Boston, MA, USA: IEEE, Jul. 2016, pp. 6640–6645. doi: 10.1109/ACC.2016.7526716.
[15] A. Buch and L. L. Bucciarelli, "Getting Context Back in Engineering Education," in *International Perspectives on Engineering Education: Engineering Education and Practice in Context, Volume 1*, S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, Eds., Cham: Springer International Publishing, 2015, pp. 495–512. doi: 10.1007/978-3-319-16169-3_24.
[16] M. Hernández-de-Menéndez, A. Vallejo Guevara, J. C. Tudón Martínez, D. Hernández Alcántara, and R. Morales-Menendez, "Active learning in engineering education. A review of fundamentals, best practices and experiences," *Int. J. Interact. Des. Manuf. IJIDeM*, vol. 13, no. 3, pp. 909–922, Sep. 2019, doi: 10.1007/s12008-019-00557-8.
[17] J. Bylander and M. Gustafsson, "Improved content mastery and written communication through a lab-report assignment with peer review: an example from a quantum engineering course," *Eur. J. Phys.*, vol. 42, no. 2, p. 025701, Mar. 2021, doi: 10.1088/1361-6404/abcb57.
[18] H. Søndergaard and R. A. Mulder, "Collaborative learning through formative peer review: pedagogy, programs and potential," *Comput. Sci. Educ.*, vol. 22, no. 4, pp. 343–367, Dec. 2012, doi: 10.1080/08993408.2012.728041.

First Author

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Logan Perry is an Assistant Professor of Engineering Education in the Department of Civil & Environmental Engineering. His work contains a unique blend of engineering education and civil engineering projects. Dr. Perry's current work centers on understanding how students transfer their knowledge between engineering school and work. This is supplemented by his interests in virtual and augmented reality, and diversity, equity, and inclusion in the context of engineering. Dr. Perry's expertise in both the engineering education and civil engineering domains provide him with a unique skillset that drives his interests in learning and technical engineering work.

Author contributions

Dr. Kaycie Lane - conceptualization of the study, data gathering and analysis, manuscript writing

Dr. Logan Perry - manuscript writing and contextualization of results in literature

Supplemental Information

Table S1: Expanded UNL Student outcome #2 definitions

Performance Indicators	4 - Exemplary	3 - Proficient	2 - Apprentice	1 - Novice
(A) Generates and analyzes possible design solutions that address requirements and constraints, and incorporate relevant design standards.	Generates multiple possible solutions, with comprehensive and adequate evaluation of those solutions	Generates multiple possible solutions, with adequate evaluation of those solutions	Generates and evaluates a single solution	Generates a single solution, no evaluation of that solution
(B) Considers impact of design on public health, safety, and welfare	Comprehensively and adequately analyzes impacts on public health, safety, and welfare	Adequately analyzes impacts on public health, safety, and welfare	Analysis of impacts on public health, safety, and welfare is incomplete and/or does not address all three aspects (i.e., health, safety, welfare)	Fails to analyze impacts on public health, safety, and welfare

(C) Considers impact of design on global, cultural, social, and environmental factors	Comprehensively and adequately analyzes impacts on global, cultural, societal, and environmental factors	Adequately analyzes impacts on global, cultural, societal, and environmental factors	Analysis of impacts on global, cultural, societal, and environmental factors is incomplete and/or does not address all four aspects (i.e., global, cultural, societal, and environmental factors)	Fails to analyze impacts on global, cultural, societal, and environmental factors
(D) Considers impact of design on economic factors	Comprehensively and adequately analyzes economic factors related to design	Adequately analyzes economic factors related to design	Analysis of economic factors is incomplete	Fails to analyze economic factors
(E) Selects an acceptable design solution and completes the design, as appropriate	Most appropriate design solution is selected in light of considerations outlined in Performance Indicators (B), (C), and (D), and design is completed to the degree required	Selected design solution is appropriate in light of considerations outlined in Performance Indicators (B), (C), and (D), and design is mostly completed to the degree required	Selected design solution does not account for some of the considerations outlined in Performance Indicators (B), (C), and (D), and design is partially completed as required	Selected design solution is inappropriate in light of considerations outlined in Performance Indicators (B), (C), and (D), or design is not completed as required

Pre-Class Survey Questions

Quiz Instructions

This quiz is designed to give me a bit of information about how much you think you know about global, cultural, social, economic, environmental and other factors related to engineering design. As part of the accreditation process for our university, we are asked to reflect as teachers on how much students know about and can articulate ideas related to global, cultural, etc. factors that you will need to be aware of in your future profession. Please answer all the questions! This is anonymous and no one except for Dr. Lane will have access to the results.

Question 1 — 1 pts

Prior to this class, how well do you think you understand global, social, cultural, economic, and environmental factors that influence and are influenced by engineering design?

- ○ Not well, I'd be uncomfortable doing this on my own
- ○ Some knowledge, I have at least seen one of these factors before
- ○ Well, I have seen at least three of these factors before
- ○ Well, I think I understand these factors well enough to try to explain to others
- ○ Really well, I feel comfortable with this factor

Question 2 — 1 pts

How well do you think you understand global, social, cultural, environmental and economic factors related to drinking water and wastewater design?

- ○ Not well, I'd be uncomfortable doing this on my own
- ○ Some knowledge, I at least remember a factor mentioned in class
- ○ Well, I know we've talked about some factors in class but I'm not sure I could identify factors myself
- ○ Very well, I think I can identify factors on my own

Question 3 — 1 pts

Have you talked about global, social, cultural, environmental OR economic factors in other classes?

- ○ Yes
- ○ No
- ○ Not explicitly
- ○ Don't remember

Question 4 — 1 pts

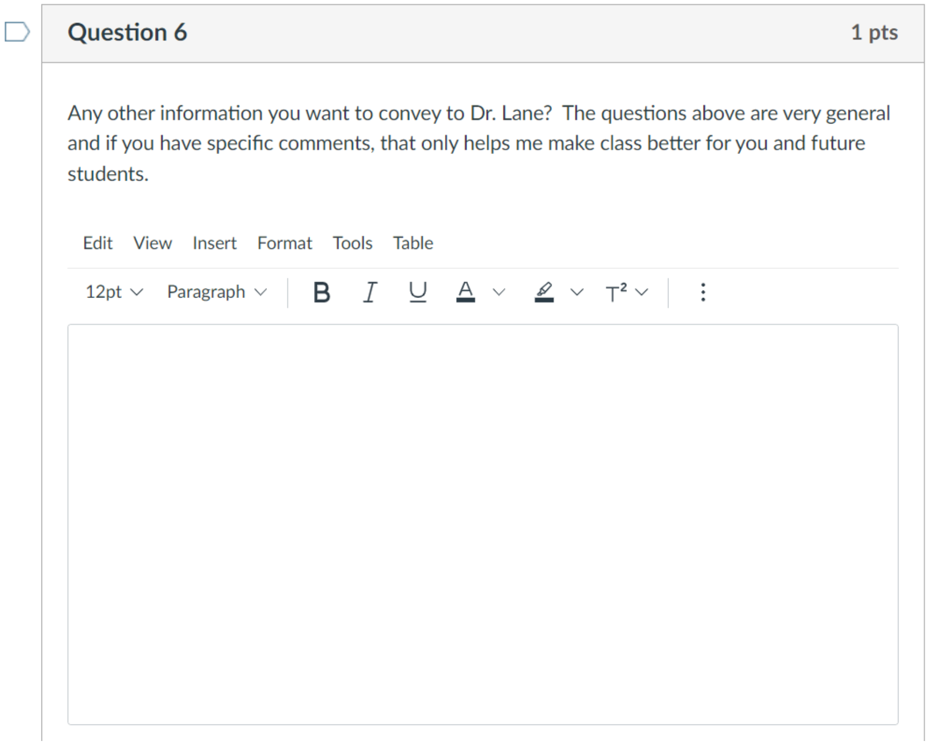
How confident do you feel about designing a solution for your Group Project community (based only how well you can design calculations)?

- ○ Help!
- ○ Not confident
- ○ Somewhat confident
- ○ Confident
- ○ Very confident

Question 5 — 1 pts

How appropriate do you think your design solution is for your group project community at the START of the class today?

- ○ Not sure
- ○ Not Appropriate
- ○ Somewhat Appropriate
- ○ Appropriate
- ○ Very Appropriate


Question 6 1 pts

Any other information you want to convey to Dr. Lane? The questions above are very general and if you have specific comments, that only helps me make class better for you and future students.

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In-Class Design Scenario

You have been hired by the town board president (Dr. Lane) of a small community in rural Nebraska to help design water and wastewater infrastructure for the community. After emailing the town board president, you learn that the community is located in a very rural area where there are no paved roads and access can be difficult in winter months. There are approximately 65 homes that the town wants to connect to some kind of centralized services with approximately 4 people per home. The town has a church, an elementary school and a high school, two restaurants, a laundromat and one bowling alley. Currently, each household is not connected to a centralized drinking water plant, each person using either a private well or relying on water haulers (trucks) to deliver water to a household storage tank. Some homes have onsite wastewater treatment in the form of septic tanks but others have very basic latrines and no homes are connected to a centralized wastewater system. Homes are generally located far away from each other which the town board president admits makes putting a centralized system in place difficult logistically. The town wants to have at least one of these services (drinking water or wastewater) centralized to start with, and the other can remain onsite if necessary.

This is all of the information you are initially presented about the community. Any other information you will need to find out by asking the town board president in order to make decisions about how to design the system.

Group Project Description

CIVE 420 - Environmental Engineering Process Design
Semester Project (40% of Final Grade)

Project Description:
Over the course of the semester, students will work in groups to apply knowledge gained in this course to a real world water and wastewater need in the United States. Small, rural communities across the United States are challenged by resource constraints and need applicable technologies and system specific designs in order to specifically address their community needs. One such region in the United States is Appalachia, where water quality concerns, geographic remoteness and aging infrastructure have all resulted in a water and sanitation crisis in our own country. DigDeep Right to Water Project is a human rights organization focused on closing the water and sanitation access gap in the United States. Appalachia Water Project (AWP) is a DigDeep project office based in McDowell County, West Virginia. AWP works directly with underserved communities and local utilities to implement creative solutions that meet unique needs of Appalachia. Over the course of the semester, students will help AWP by providing water and wastewater quality analyses and designing both a water treatment solution and a wastewater/resource recovery solution.

There are several resources and links on Canvas to the AWP:
https://canvas.unl.edu/courses/150810/modules/items/3906723

Over the semester, students will be responsible for the following deliverables, which are cumulative components of a final report:

- Student definition of the scope of the problem – using information from AWP, students will write a 2-3 paragraph description in their own words of the water and wastewater problems faced in Appalachian communities
- Water Quality Report – Students will use data provided by AWP to create a 1 page memo of water quality results that can be used to inform communities of the most pressing water quality issues that need to be addressed.
- Initial Water Treatment Design – using the Water Quality Report and information provided by AWP, students will use knowledge learned in this course to propose an initial water treatment design for the Appalachian communities, which at a minimum, must include 2 design calculations for the selected water treatment technologies or processes
- Midterm Presentation - five minute presentation per group on the water quality analysis and water treatment design components
- Wastewater/Resource Recovery Memo – students will have the option to submit ONE of the following as the deliverable for this activity: (1) a 1 page memo describing the wastewater

quality in the Appalachian community (indicating potential treatment options OR (2) a 1 page memo describing how resources (such as nutrients, energy, etc.) can be recovered from wastewater and used by the community.

- Initial Wastewater/Resource Recovery Design – students will use the Wastewater/Resource Recovery Brief to propose a treatment solution or technology to aid Appalachian communities in treating or utilizing wastewater. At a minimum, the initial design must include at least 2 design calculations
- Final Report – students will use all of the previous deliverables (Water Quality report, Initial Water Treatment Design, Wastewater/Resource Recovery Brief, Initial Wastewater/Resource Recovery Design) to generate a finalized design and report to present to AWP in a final presentation session at the end of the semester.
- Final Presentation - each group will present the results of their final report in a 10–15 minute presentation.

Project Data
DigDeep Community Data Page: https://fuchsia-burn-eda.notion.site/CIVE-420-Semester-Project-32afcbd6f12d42a0b5d09149fa7c388d

Project Components
This project is designed to be completed in stages so that by the end of the semester each of the components you complete during the semester are integrated into your final report. The expectation is that your group revises each component based on feedback from Professor Lane and AWP and incorporates edits into the final report. Each of the components is laid out below in detail.

Component	Proposed Due Date
Scope of Work	Friday February 10h at 5:00pm
Water Quality Memo	Friday February 17th at 5:00pm
Initial Water Treatment Design	Friday March 10th at 5:00pm
Midterm Presentation	Friday March 10th at 5:00pm
Wastewater Effluent/Resource Recovery Memo	Friday April 7th at 5:00pm
Initial Wastewater Treatment Design	Friday April 28th at 5:00pm
Final Report	Friday May 12th at 5:00pm
Final Presentation	Week of May 8th - either May 9th or 11th