Surviving the Storm: An Assessment of Natural Hazards Experiential Learning Activities for Civil Engineering Students Facing a Changing World

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ABSTRACT

Future civil engineers need to be equipped to tackle the challenges of a changing world. The American Society of Civil Engineering highlights many needs for civil engineers of the future including a strong foundation in sustainable design, quick adoption of emerging technologies, and the ability to use innovative problem-solving strategies [1]. Education is integral in helping students develop professional skills and uniquely equipped to impact future engineers. The following paper describes the curricula and assessment tools used in a one-week summer course, introducing high school students to civil engineering concepts in sustainable designs, new technologies, and innovative problem-solving techniques. This study evaluates the course's effectiveness in motivating and encouraging students to think critically about the challenges civil engineers will face in the future. Students are exposed to challenges, including increasingly severe natural hazards, limited resources for infrastructure construction (or rehabilitation), and socio-economic barriers to equitable infrastructure access. This paper details educational components, including (1) a board game on resource allocation during a natural disaster, (2) augmented reality technologies used to visualize design and construction features, (3) a reconnaissance mission (field trip) focused on carbon footprint and alternative construction materials, and (4) an open-ended project to design a structure in an area affected by compounding hazards. The course assessment was based on student artifacts, pre- and post-course surveys, and anonymous feedback surveys. Overall, the authors found evidence that suggests students were motivated to use the concepts learned in class and have expanded their knowledge on topics related to natural hazards. These findings are essential to the civil engineering community as they inform that placing new and challenging topics in experiential learning activities can ease their implementation in the curricula. Future work will focus on revising new issues for the engineers of the future and developing activities to present them in an interactive environment.

Keywords: civil engineering, natural hazards, hands-on activities, experiential learning

INTRODUCTION

Civil engineers and civil engineering infrastructure will face many new and increasingly severe challenges in the next 50 years. Infrastructure will need to withstand extreme events at increased frequency and intensity, and the negative impact of infrastructure on the environment and surrounding communities will need to be reduced. Engineers must be effectively prepared to develop and apply innovative technologies to take on these challenges. The American Society of Civil Engineering (ASCE) echoes this priority, identifying pillars of civil engineering education, including equipping civil engineers with a strong foundation in sustainable design, confidence and proficiency in emerging technologies, and the use of innovative problem-solving strategies [1].

Engineering educators play a critical role in preparing students to meet these challenges. They can inspire and guide the next generation of civil engineers. Recognizing this, instructors at Purdue University designed a course to introduce high-school students to civil engineering and future challenges facing infrastructure. Through experiential learning, students gained first-hand exposure to engineering concepts, ultimately motivating them to pursue engineering at the undergraduate level.

To be eligible to participate in this summer course, students must be enrolled in a U.S.-based high school and enter their junior or senior year of high school after completing the summer course. The week-long course had 53 students divided into two cohorts. The course emphasized resilience and sustainability in the design of civil infrastructure and integrated design approaches. Traditional design approaches account for hazards including earthquakes, hurricanes, and fires but consider these hazards separately and without considering any cascading effects (i.e., fire following an earthquake or successive hurricanes affecting adjacent locations). Integrated design approaches allow for enabling more resilient and efficient infrastructure design. They allow engineers to address current and future challenges in both environmentally and economically sustainable ways. Students were introduced to these approaches through active learning techniques facilitated by a team of five graduate student instructors enrolled in PhD programs in civil engineering at Purdue.

Pre-college engineering programs have been integral to the engineering pipeline for decades. Many student participates in these programs have gone on to become successful engineering students including underrepresented students [2], [3]. More than just increasing representation, these programs can also help students develop a sense of engineering identity [4], self-efficacy [5], [6], [7] and persistence in engineering programs [8], [9]. Nevertheless, several studies also saw limited to no increase in student achievement with participation in these programs [3], [10], suggesting that merely offering a program does not translate to the program being effective in increasing student achievement. Instead, effective programs and follow-on assessments are necessary to identify what works well (and should be continued and promoted) and elements that do not support program outcomes.

Many engineering students have benefited from experiential learning activities, including using technology to promote innovative engineering problem-solving. For example, introducing robotics into the classroom has shown an improvement in student interest in engineering fields

[11]. Similarly, engineering board games and phone or computer games have been developed and deployed successfully [12]. Another program has developed remotely operated underwater vehicles [13]. The program discussed herein similarly relies on employing novel technologies for engineering problem-solving applications.

COURSE CONTENT

The instructors incorporated various activities designed to introduce pre-college students to the stages of a civil engineering project and the application of novel technologies to enhance design and construction. These elements featured hands-on in-class activities and site visits.

All activities were aligned to support student groups in designing a resilient single-story tiny house. The students learned through the course that civil engineers must design infrastructure that can safely operate before, during, and after a hazardous event. Students then had to identify the hazards that affected their worksite on a fictitious Purdue hazard map and choose appropriate design options to withstand such hazards. Appendix A presents an example of hazard maps and calculation spreadsheets. Hazards included earthquakes, fire-prone zones, flooding, hurricanes, and landslides. Each team was required to provide a cohesive and resilient tiny house design, cost estimate, and carbon footprint estimates. The final deliverable was a poster and a team presentation to the instructors and guests.

See below for an abridged version of the project prompt:

> *Civil engineers must design and build infrastructure that can safely operate before, during, and after a hazardous event. Designing and building resilient infrastructure involves identifying hazards, choosing appropriate design options and construction practices to withstand such hazards, and using modern technologies to improve a community's quality of life. Work in teams to provide a resilient design for a single-story tiny house on the hazardous Purdue campus.*
>
> *You will be provided with the following material to complete your project:*
> - *Hazard maps for team project locations*
> - *Project catalogs to choose materials and finishings for your tiny house design*
> - *Cost and carbon footprint estimate spreadsheet*
> - *Project presentation grading rubric*
> - *Poster template for presentation*

Examples of course components that helped students develop the skills and critical thinking needed to approach this project included:

- <u>Board Game:</u> The "Keep Us Safe!" board game was designed to simulate the decision-making process in disaster management. We chose mitigation of hurricane damage as a specific case. In this interactive activity, students were divided into teams, each with a set of 20 "Mitigation Action Cards" categorized into Standard and Dependent types. Each card represented a strategic action with specific costs, implementation times, and potential to protect residents from an impending hurricane threat. The teams were

challenged to formulate a plan that maximized safety while adhering to budgetary constraints and time limitations. The goal of the game was to create an effective mitigation plan that (1) kept the most possible people safe, (2) used the least possible amount of money, and (3) was implemented within 96 hours, the time at which the hurricane was expected to hit the city. The score was computed using the following formula: $\text{Score} = a \times \#\text{ of Safe People} + b \times \text{Cost} + c \times (96 - \text{Time})$.
The activity gave students practical insight into resource management and prioritization, which are critical in civil engineering projects. It also incorporated a scoring system that quantitatively assessed the effectiveness of students' decisions based on people protection, cost efficiency, and timeliness. Figure 1 shows an example of playing cards developed for this activity.

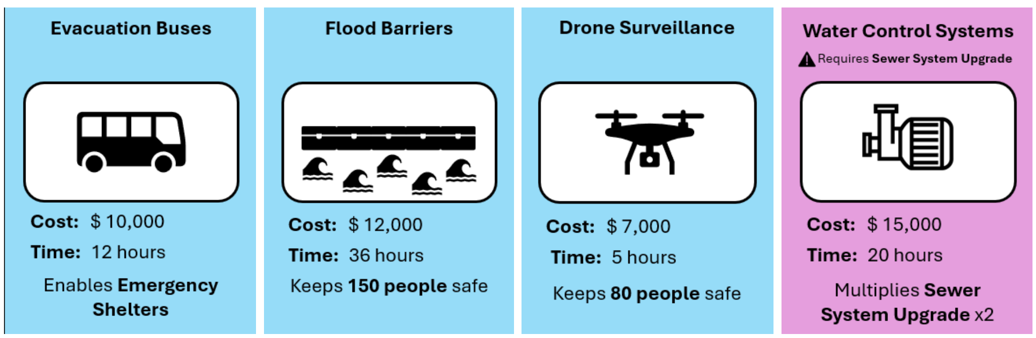


Figure 1. Example of cards from Keep Us Safe! board game activity

- <u>Mixed Reality (MR):</u> Students were organized into teams, and each team used a Trimble XR10 headset to stream into a computer and visualize a digital house design in the classroom (i.e., using mixed reality). The students took turns using the headset while other group members pointed out model features to the headset operator. This activity exposed the students to how frontline workers use modern technology to overlay design models in 3D space and identify construction or functionality issues in potential designs. Figure 2 shows a picture of MR technology in action.


Figure 2. MR technology depicting a house model

- Reconnaissance Mission: In conjunction with the tiny house project, the students visited the site for their projects. The reconnaissance missions to their project site included: i) picking a specific location for their house; ii) testing their design floor layout using wood garden stakes, measuring tape, and utility string; and iii) adding objects to their layout using augmented reality. By completing these activities, the students could identify the relationship between space and their design's physical features (e.g., dimensions). Figure 3 shows a student group working on the reconnaissance mission of their project site.

Figure 3. Student group working on reconnaissance mission

The course components, such as lesson plans and the class schedule, were chosen to foster the knowledge needed for students to approach the final project. The instructor team met weekly to coordinate their plans, collect feedback, and incorporate team activities that apply the various engineering concepts learned in the classroom. These meetings were critical to ensuring the alignment of activities and lessons to achieve the intended learning outcomes.

COURSE ASSESSMENT

The course effectiveness was assessed using pre-course (N = 53), post-course (N = 53), and feedback (N = 50) surveys as well as student artifacts. Since the final project (N = 17) relied on student engagement in a combination of in-class activities and out-of-class assignments, this student artifact represented student learning throughout the course duration.

Two types of survey instruments were used to assess the course. Pre- and post-course surveys were administered at the beginning and end of the course, and anonymous feedback surveys were administered after the course concluded. Together, these tools were used to quantify if the experiential learning activities employed resulted in students meeting course outcomes like being interested in civil engineering as a career, developing a methodology for approaching engineering problems, and knowing technologies that could be used in cities of the future.

The assessment questions used are listed in Table 1. Questions 1-5 were on a Likert scale from strongly disagree to strongly agree, while questions 6 and 7 were open-ended. Answers from questions 1-5 were assigned numeric values from 0 (strongly disagree) to 4 (strongly agree) for analysis. Answers from the open-ended questions were deidentified, then analyzed by an independent researcher, and coded based on themes and similar phrases in the responses.

Table 1. Assessment questions from the course surveys

Course components	**Questions**
Pre- and post-course surveys (Likert scale)	1. I can think through an engineering problem and propose solutions.
	2. I understand the relevance of civil engineering in real-life problems.
Anonymous feedback survey (Likert scale)	3. I believe what I learned in this course is important.
	4. This course encouraged me to consider a career in civil engineering.
	5. I want to apply what I learned during the course in the future.
Pre- and post-course surveys (open-ended questions)	6. What should engineers think about when designing tomorrow's infrastructure?
	7. Which technologies are engineers using to design and build tomorrow's infrastructure?

As seen in Figure 4, students enrolled in this course generally believed they could think through engineering problems and propose solutions at the beginning, although their belief grew from the start to the end. Similarly, students widely identified as understanding the relevance of civil engineering to real-life problems, but their agreement with the statement was even stronger; nearly all "strongly agree" at the conclusion of the program.

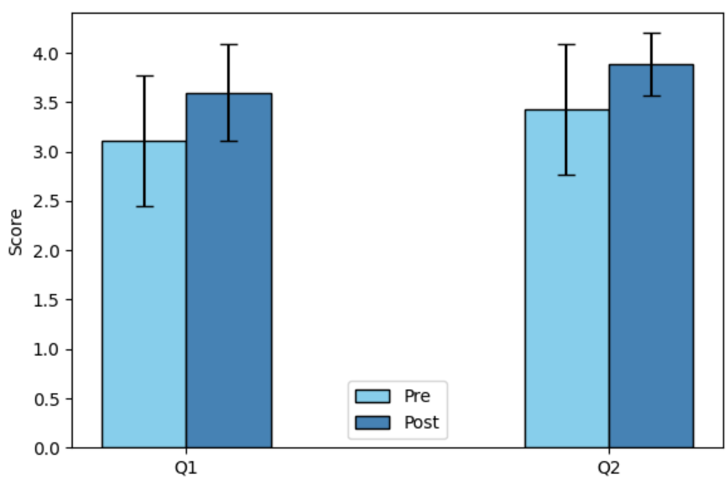


Figure 4. Pre- and Post- Course Survey Results from Questions 1-2

In the feedback survey, students agreed at a similar level to Questions 3 – 5 (see Figure 5), indicating that they consistently found the topic important, were encouraged to consider civil engineering as a career, and want to apply their learning to future courses. This feedback indicated that program outcomes including being interested in civil engineering as a career, are being met through the curriculum.

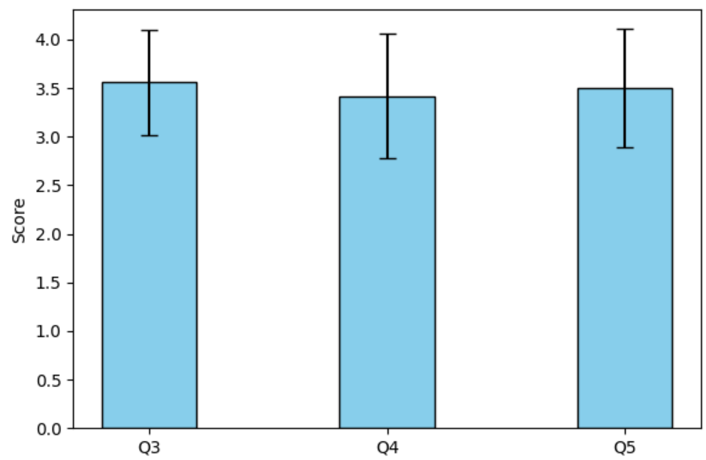


Figure 5. Feedback Survey Results from Questions 3-5

Finally, findings from the open-ended questions were used to evaluate students' perspectives on considerations for future infrastructure design (Q6) and technologies that could be employed in future cities (Q7). Student responses were coded based on long-form responses (i.e., one response can be listed under multiple categories). A sample of this coding, corresponding to the responses of Q6 and Q7, is shown in Table 2. At least four students needed to mention a topic in the combined pre- and post-course survey to be included in this table.

As seen in Table 2 Q6 responses, the most common initial response was on Human-Centered Design, while post-course surveys identified Service Life and Human-Centered Design. Moreover, in initial pre-course surveys, no responses discussed Technological Advancement, while many students' post-course responses did. This change in response correlates with the experiential activities students participated in during the week, such as the hazard mitigation board game and reconnaissance mission. These results suggest that students were exposed to these ideas and could see their importance for future engineering infrastructure designs. Although these results support the course’s outcomes, they may also indicate that students now had more precise or technical language to describe the purpose of infrastructure. For example, students may talk about buildings being safe during a hurricane initially but something more like infrastructure being resilient to natural hazards after the course.

As seen in Table 2 Q7 responses, students identified many existing and emerging technologies used to design and build new infrastructure. Overwhelmingly, students knew about computer-aided drafting software prior to the course, with some students also mentioning surveying technologies or construction automation. After the course, students mentioned many additional technologies, including Building Information Modeling (BIM), Augmented and Virtual Reality (AR/VR), and 3D printing. These technologies overlapped with course activities like using Mixed Reality headsets. This change in response further supports the course outcome of knowing existing and emerging technologies applicable to future infrastructure projects.

Table 2. Student responses from the pre- to post-course surveys for questions 6 and 7.

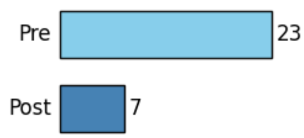
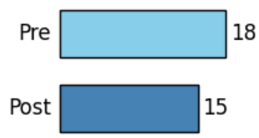
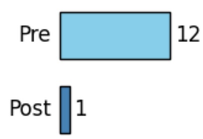
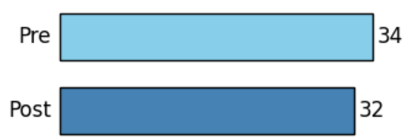
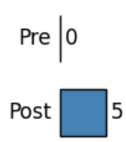
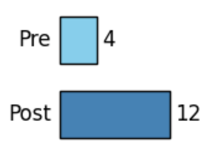
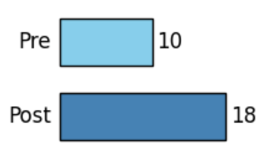
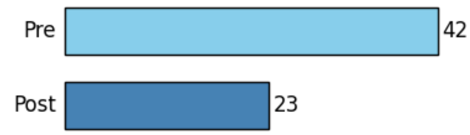
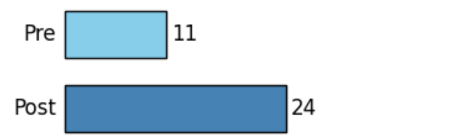
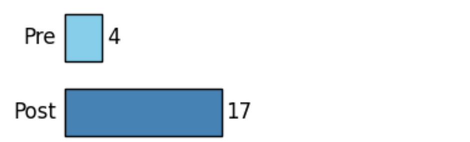
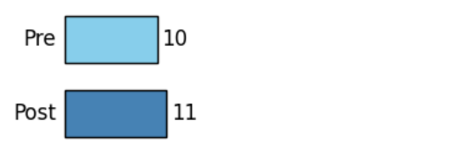
Topic	**Frequency**	**Comment**
Question 6		
Sustainability and Environmental Impact		"How to create infrastructure that promotes **good environmental practices** while being sustainable for the future and meeting the needs of the people"
Service life		"Engineers should think about the **lifespan of a structure**, how it will be built"
Cost and Efficiency		"**Budget**"
Human-Centered Design		"**Accessibility, ease of use, and comfort**, and safe"
Technological Advancement		"**Future technology**"
Hazard Mitigation and Disaster Resilience		"The community, sustainability, **hazards**"
Social and Ethical Development		"How it will **impact the community** and how it will last for years to come"

Table 2 (continued)

Topic	**Frequency**	**Comment**
Question 7		
Computer-Aided Design		"**CAD**, virtual reality, 3D printing"
Data Management (BIM)		"**BIM**, revit, cad, robots, ai, vr"
Surveying Technology (LiDAR, Drones)		"**Drone,** camera, AR, mixed reality"
Immersive Technologies (AR, VR)		"**AR, VR**, LiDAR"
3D Printing		"**3D printing**, BIM, AR"
Construction Tech Machines and Robotic		"BIM, **robotics**"
New Materials		"3D printing, drones, **composites**"
Artificial Intelligence		"**AI**, drones, AR, VR, 3D modeling, 3D printing"

In addition to the course surveys, the final project poster was analyzed for evidence of student learning. The posters were evaluated using a rubric developed to assess students' ability to describe natural hazards, develop a reasonable solution for each hazard, use evidence effectively to support their selected solution, and employ reasonable sustainability practices. This rubric is included in Appendix B. This rubric (and the assessment herein) was separate from rubrics and grades used to evaluate students taking the course. The researchers determined that achieving 8 points demonstrates proficiency in applying natural hazards based on the criteria developed in the rubric.

A researcher unaffiliated with the course assessed the posters using the rubric developed. The researcher found that student teams achieved an average of 9.23 out of 12 points, with a standard deviation of 1.99. This assessment further supports the students' ability to use the concepts introduced in class and apply them to their tiny house project.

CONCLUSIONS AND FUTURE WORK

The results presented in this study support that experiential, hands-on learning activities meaningfully engaged students in real-world civil engineering concepts and increased their awareness of resilience, sustainability, and emerging technologies. Pre- and post-course survey data showed that participants gained confidence in thinking critically about engineering problems and their relevance to everyday life. Open-ended feedback further suggested that the students became more cognizant of the broader social demands of future infrastructure and the essential role of innovative, sustainable designs. These findings emphasize that placing new and challenging topics into experiential learning activities, such as the natural hazard mitigation board game and augmented reality fieldwork, can be a promising way to enhance students' interest and motivation toward engineering fields.

Future work will focus on creating new activities aligned with rapidly evolving challenges in civil engineering. Expanding the curriculum to include additional hazards (e.g., impacts of climate change) and integrating emerging digital tools (e.g., introduction to machine learning) can provide students with a more holistic view of the profession. Additional in-depth assessment strategies, such as tracking students throughout time to monitor their continued interest and retention in engineering pathways, can improve the analysis provided.

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APPENDIX A

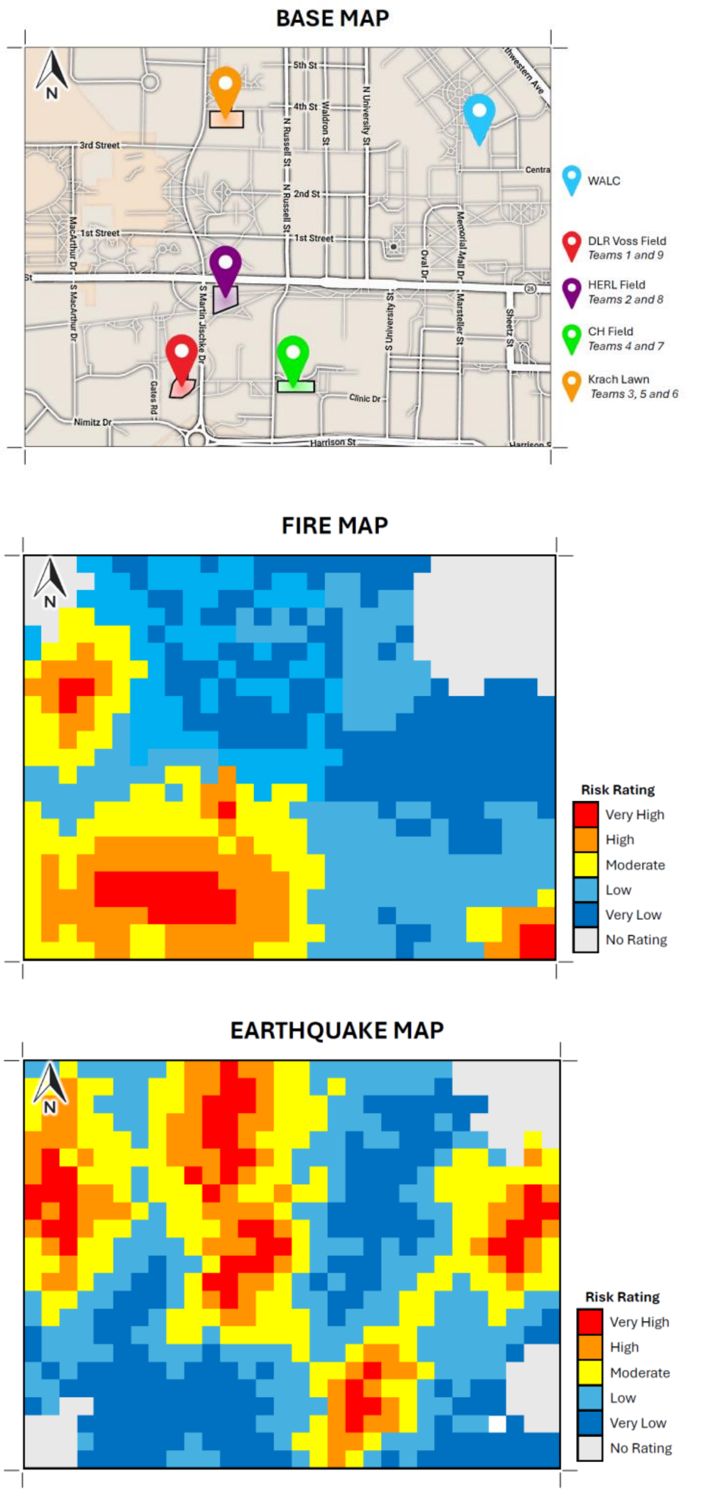

Figure 6. Example of hazard maps used in the final project

	Cost		Carbon Footprint	
Finishing	Value	Unit	Value	Unit
Floors	10	$/sqft	0.78	lb/sqft
Walls	15	$/sqft	0.47	lb/sqft
Cabinets	200	$/ft	220	lb/ft
Windows	350	$/unit	160	lb/unit
Doors (Wood)	750	$/unit	66	lb/unit
Paint	2	$/sqft	0.08	lb/sqft
Plumbing	3	$/sqft	4.41	lb/sqft

Finishings Cost ($)				Carbon footprint (lb)			
Enter your value	Unit	Calculated Value		Enter your value	Unit	Calculated Value	
0	sqft	$	-	0	sqft	0	lbs
0	sqft	$	-	0	sqft	0	lbs
0	ft	$	-	0	ft	0	lbs
0	unit	$	-	0	unit	0	lbs
0	unit	$	-	0	unit	0	lbs
0	sqft	$	-	0	sqft	0	lbs
0	sqft	$	-	0	sqft	0	lbs

Figure 7. Example of the spreadsheet for carbon footprint and cost calculations

APPENDIX B

Rubric for Evaluation of Poster

Criteria	Exemplary (3)	Proficient (2)	Developing (1)	Incomplete (0)
Description of Natural Hazards	Describes three natural hazards, including their causes, effects, and impacts on construction.	Describes three natural hazards with minor inaccuracies or lack of depth in explaining causes and impacts.	Describes one or two hazards or provides superficial explanations without addressing causes or impacts.	It does not describe natural hazards or provide irrelevant or incorrect information.
Proposed Solutions for Mitigating Hazards	Proposes practical, feasible solutions to all three hazards, clearly linked to the hazards described, with strong justification.	Proposes solutions for three hazards but lacks clarity, feasibility, or strong justification for one or more solutions.	Proposes solutions for one or two hazards with weak or unclear connections to the hazards or limited feasibility.	It does not propose solutions or the solutions are irrelevant or unjustified.
Evidence of Effective Use of Construction Material	Identify one piece of evidence of effective use of construction material, justify the choice, and explain its effectiveness.	Identifies one piece of evidence and justifies the material choice with some clarity but lacks detail or depth.	Identifies one piece of evidence but provides weak justification or limited explanation of its effectiveness.	Does not identify or justify a piece of evidence effectively.
Efforts to Reduce Material Use and Carbon Footprint	Proposes a reasonable design that considers geometry, material type, or layout with clear justification of sustainability impact.	Proposes a design that addresses material use or carbon footprint but lacks comprehensive justification or feasibility.	Provides a partially developed design with weak justification for material use or sustainability.	Does not propose a design or provides an unreasonable or unjustified effort.