Cultivating Entrepreneurial Mindset in Net Zero Energy Building Instruction

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Abstract

Preparing civil engineers to address decarbonization and infrastructure resilience requires integration of technical content with systems thinking and stakeholder-centered decision-making. This study presents the design and assessment of a six-week Net Zero Energy Building (NZEB) sensing challenge embedded within a junior-level civil engineering laboratory course. The module was intentionally aligned with the Kern Entrepreneurial Engineering Network (KEEN) Entrepreneurial Mindset (EM) framework, Curiosity, Connections, and Creating Value, while reinforcing technical competencies consistent with guidance from the American Society of Civil Engineers (ASCE).

Students collected and analyzed real-time building performance data with sensors, engaged with interdisciplinary experts, and developed retrofit recommendations supported by energy modeling and economic justification. A mixed-methods assessment approach evaluated cognitive depth of student-generated questions (Curiosity), interdisciplinary integration in structured reflections (Connections), and stakeholder-centered value propositions in final deliverables (Creating Value).

Results indicate measurable growth in analytical question complexity and expansion of interdisciplinary reasoning over the six-week period. Final projects demonstrated emerging capacity to translate technical analysis into stakeholder-informed recommendations, though integration of building-level metrics with whole building and system-level impacts varied across teams.

Findings of this empirical work demonstrate that EM can be intentionally embedded within technically rigorous coursework to deepen disciplinary learning while strengthening stakeholder-centered reasoning.

1. Introduction

Civil engineers entering the profession today must navigate accelerating climate change, aging infrastructure, rapid technological advancement, and increasing societal expectations for sustainable and equitable solutions [1], [2]. In response, the ASCE has identified future-focused technical competencies essential for the profession, including responsible integration of artificial intelligence, managing uncertainty in design and modeling, collecting and verifying sensing data, applying inclusive design principles, and communicating effectively through visualization tools [3]. These competencies reflect the technical complexity and socio-technical responsibility of modern civil engineering practice.

Yet technical proficiency alone is insufficient. Engineers must also think beyond calculations to recognize opportunity, integrate knowledge across domains, and design solutions that create meaningful value for stakeholders. Developing this broader orientation requires cultivating ways of thinking that complement technical skill development. One such framework is the Entrepreneurial Mindset (EM), developed by the Kern Entrepreneurial Engineering Network (KEEN) [4]. EM emphasizes three interconnected Habits of Mind: Curiosity, Connections, and Creating Value [5]. Together, these habits encourage engineers to question assumptions, integrate diverse perspectives, and translate analysis into stakeholder-centered impact [6].

Although ASCE and KEEN articulate complementary visions for future engineers, they are often implemented separately in educational contexts. Few empirically examined models demonstrate how EM can be intentionally embedded within core civil engineering coursework while advancing disciplinary competence.

This study addresses that gap by examining how a challenge-based Net Zero Energy Building (NZEB) sensing project operationalizes EM within a junior-level civil engineering laboratory course. The six-week NZEB project situates sensing and data visualization within a real campus decarbonization initiative.

Specifically, this study investigates three research questions:

> RQ1: Does student curiosity about Net Zero Energy Buildings change over the course of the challenge-based NZEB project?
>
> RQ2: What connections do students make as they progress through the NZEB modules, and how does the depth of those connections evolve?
>
> RQ3: To what extent does the project support students in developing stakeholder-centered, quantitatively supported, and systems-informed value propositions?

By empirically examining shifts in curiosity, interdisciplinary connections, and value creation via a mixed-method approach, this work contributes to the literature a replicable-instructional-model that bridges ASCE's future skillset vision with KEEN's EM framework.

2. Conceptual Framework: KEEN Entrepreneurial Mindset (EM) Framework

This study is grounded in the KEEN EM framework, which emphasizes interconnected Habits of Mind [4], [5]. Rather than positioning EM as separate from technical competence, we conceptualize it as the cognitive orientation that enables engineers to enact disciplinary knowledge in complex, uncertain, and stakeholder-driven contexts.

Below, we briefly define each habit as it informs our instructional design and assessment method.

2.1 Curiosity

KEEN defines curiosity as habits that fuel exploration, challenge assumptions, and reveal opportunity [6]. In engineering education, curiosity functions as a driver of adaptive problem solving and experimentation [7]. It motivates learners to move beyond procedural application toward deeper inquiry, especially in contexts characterized by uncertainty and incomplete information [5], [8].

Research consistently identifies curiosity as a catalyst for intellectual growth [9], [10]. It promotes question generation, reflective thinking, and iterative learning. As students gain knowledge, their capacity to ask more sophisticated questions increases, reinforcing a cycle of exploration and refinement [11]. Within engineering contexts, this progression reflects movement from surface-level understanding toward analysis, evaluation, and design-oriented thinking [12] - [15].

For civil engineers confronting climate adaptation, sensing uncertainty, and infrastructure resilience, curiosity supports:

- Questioning accepted assumptions
- Seeking higher-quality data
- Investigating system interactions
- Identifying emerging opportunities for improvement

In this study, curiosity is assessed through the cognitive depth of student-generated questions about NZEB. By examining how the sophistication of questions evolves over time, we assess whether students shift from definitional or procedural inquiries toward analytical and systems-oriented thinking.

2.2 Connections

Connections refer to habits of integrating ideas across domains to generate insight and innovation [6]. This construct closely aligns with systems thinking, the ability to understand relationships among technical, economic, environmental, and social components within complex systems [15] - [17].

Civil engineering problems are inherently socio technical. Decisions about materials, energy systems, retrofits, and infrastructure investments involve knowledge synthesis from domains including but not limited to thermodynamics, economics, policy, public health, stakeholder behavior, and long-term sustainability tradeoffs. Creative decision-making therefore requires integration rather than isolated technical optimization [19]. Educational research on interdisciplinary learning and sustainability emphasizes that students must learn to recognize interdependencies, frame problems through multiple lenses, evaluate consequences across system boundaries, and incorporate diverse stakeholder perspectives [19] - [21].

Within the NZEB project, connections emerge as students link:

- Thermal imaging data to building science
- Energy Use Intensity (EUI) metrics to economic return
- Social Cost of Carbon (SCC) calculations to policy frameworks
- Retrofit decisions to stakeholder and community impact

In this study, connections are examined through reflective writing following guest lectures, allowing us to analyze how students articulate interdisciplinary integration, systems reasoning, and professional relevance over time.

2.3 Creating Value

Creating value represents habits that drive action toward meaningful outcomes that benefit stakeholders and society [6]. In engineering contexts, value extends beyond technical accuracy to include feasibility, impact, sustainability, and alignment with user needs [22] - [24].

For civil infrastructure projects, value creation requires:

- Identifying stakeholder motivations
- Quantifying tradeoffs (e.g., energy savings, ROI, carbon reduction)
- Balancing short-term constraints with long-term impact
- Communicating solutions effectively
- Persistence through failure

Value is inherently contextual and multi-dimensional, encompassing financial, environmental, social, and operational considerations. Engineering decisions generate value when technical design is aligned with stakeholder priorities and system-level outcomes [25].

In the NZEB challenge, students move from data analysis to actionable retrofit proposals. They are required to justify recommendations using Energy Use Intensity (EUI), Social Cost of Carbon (SCC), embodied carbon (EC), return on investment (ROI), and stakeholder considerations. In this study, creating value is therefore assessed through the quality of final project reports, specifically the degree to which students translate technical analysis into evidence-based, stakeholder-centered value propositions.

2.4 ASCE Technical Competencies and EM

The effective enactment of the ASCE future-oriented technical skills depends on underlying cognitive habits. Therefore, we conceptualize KEEN EM as the enabling mechanism for these ASCE competencies. Accordingly, the NZEB project was intentionally designed as a challenge-based learning experience that integrates sensing technologies, sustainability metrics, and stakeholder decision-making within a real campus decarbonization initiative. Rather than treating sensing as a purely technical exercise, the project positions data collection, modeling, and analysis within broader economic, environmental, and social tradeoffs. Students are required not only to collect accurate measurements, but also to interpret uncertainty, connect findings across domains, and translate results into actionable value propositions.

The following section describes the instructional design of the NZEB challenge and the study context.

3. Instructional Design and Study Context

To operationalize EM within a required sensing course, we designed a six-week NZEB challenge-based learning experience embedded within a junior-level sensing laboratory. The project integrates building science, sensing technologies, sustainability metrics, and stakeholder decision-making within an authentic campus decarbonization context. This section describes the course setting, the instructional design of the NZEB challenge, and the intentional alignment between learning objectives, EM Habits of Mind, and ASCE technical competencies.

3.1 Course Context

This course is part of a vertically integrated sensing curriculum in our department, designed to progressively develop students' competencies in data collection, instrumentation, and analytical modeling across multiple levels of the undergraduate program [26].

After the sophomore-level sensing course introduces foundational sensing principles and instrumentation, this junior-level course emphasizes experimental design, uncertainty quantification, data interpretation, and effective communication of findings. The 14-week semester-long course enrolls approximately 16-20 students each spring. The NZEB challenge was implemented during the second half of the spring semester.

3.2 NZEB Challenge Instructional Design

The NZEB project was structured as a six-week challenge-based learning (CBL) experience grounded in an authentic institutional goal: achieving 70% decarbonization of campus buildings by 2030 under a local sustainability framework. University facilities data, including EUI records, provided a realistic foundation for analysis, positioning the campus as a "living laboratory" for applied sustainability.

The project followed three progressive phases aligned with established CBL principles:

Engage (Weeks 1–2: Curiosity & Framing the Challenge)

Students were introduced to Net Zero Energy concepts, energy performance metrics, embodied carbon, and the SCC. They examined campus EUI data, explored sustainability certifications, and generated questions about building performance. This phase emphasized inquiry, problem framing, and identification of knowledge gaps.

Investigate (Weeks 3–5: Connections & Systems Integration)

Students deployed thermal imaging cameras and temperature sensors to evaluate building envelope performance and identify thermal bridging. They designed data collection protocols, analyzed heat flux patterns, assessed uncertainty and measurement limitations, and interpreted findings in relation to building thermodynamics.

Guest lectures from architects, engineers, and sustainability professionals expanded the analytical frame beyond technical performance. Students connected sensing data to economic tradeoffs, policy considerations, occupant comfort, and retrofit feasibility. This phase required interdisciplinary integration and systems-level reasoning.

Act (Weeks 5–6: Creating Value & Decision-Making)

In the final phase, student teams synthesized their findings into retrofit proposals tailored to stakeholder constraints and budgetary limits. Deliverables included:

- Thermal performance analysis, before and after retrofits
- EUI and SCC calculations

- Three retrofit alternatives with ROI and NPV estimates
- A stakeholder-centered value proposition

Students presented their recommendations to university facilities representatives and invited practitioners, reinforcing the authenticity and accountability of the task. Across phases, sensing functioned as a decision-enabling tool embedded within environmental, economic, and social systems. Figure 1 illustrates the progressive integration of Curiosity, Connections, and Creating Value across the Engage, Investigate, Act phases, demonstrating ASCE competencies alignment.

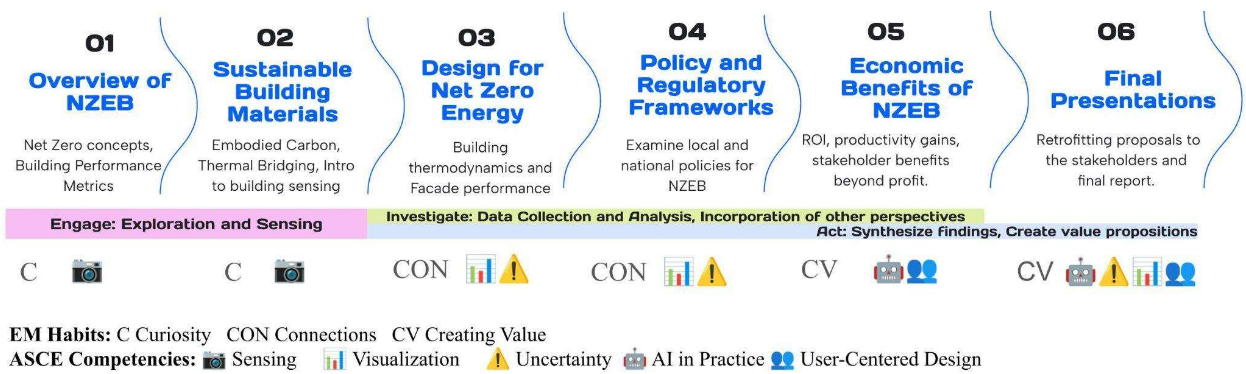

Figure 1: Curriculum Architecture of the Net Zero Energy Building Challenge-Based Learning Project Weekly Modules 1-6

3.3 Learning Objectives Alignment

The NZEB challenge was intentionally designed to align EM Habits of Mind with ASCE's identified future technical competencies. Rather than layering mindset onto technical work, the instructional architecture embedded EM within core technical tasks. Table 1 details the mapping between NZEB challenge learning objectives, EM Habits of Mind, and ASCE technical competencies.

By structuring the NZEB challenge around inquiry, integration, and stakeholder-centered decision-making, the instructional design positioned EM as the mechanism through which students enacted disciplinary knowledge.

Table 1: Learning Objectives of NZEB Mapped to EM Habits of Mind and ASCE Technical Skills

Learning Objective	EM Habit of Mind	ASCE Technical Skill(s)
Use thermal imaging/sensing technology to analyze building facades for thermal bridging.	Curiosity: Gather data and information to support ideas	Sensing
Develop understanding of infrared cameras to explore their potential in evaluating building performance.	Curiosity: Formulate salient questions	Visualization
Identify campus buildings for investigation, select structural members, and design/implement a testing protocol to collect thermal imagery and data.	Curiosity: Take ownership and express interest in the topic	Working With Uncertainty; Sensing
Identify problems associated with current building materials and their carbon footprint.	Curiosity: Self-reflect and evaluate preconceived ideas and accepted solutions	User-Centered Design
Develop a Net Zero Energy blueprint using a sustainability framework and ROI strategies; analyze energy use, EUI, CO_2 emissions, and SCC.	Curiosity: Critically observe interconnected systems to recognize opportunity	User-Centered Design; Working with Uncertainty
Determine which proposal or method most effectively supports decarbonization aligned with Pittsburgh 2030 goals.	Curiosity: Explore multiple solution paths	Working with Uncertainty; AI in Practice

Define civil engineers' roles in climate change, urban sustainability, equity-centered design, and decarbonization strategies (e.g., green roofs and structural load).	Connections: Consider a problem from multiple viewpoints	User-Centered Design; Working with Uncertainty
Assess limitations of IR cameras, evaluate information sources, and strategize improvements to data accuracy.	Connections: Identify and evaluate sources of information	Sensing; AI in Practice; Working with Uncertainty
Communicate findings clearly to non-experts to create value through understanding.	Creating Value Articulate ideas to diverse audiences	Visualization; User-Centered Design
Develop a business case for system and investment projects; propose three retrofit options; evaluate energy savings, ROI, NPV, stakeholder benefits, ecological footprint, and embodied carbon.	Creating Value: Craft a compelling value proposition for stakeholders	AI in Practice; Working with Uncertainty; Visualization
Assess design sustainability and scalability.	Creating Value: Describe how an idea could be scaled and sustained, including revenue streams, key resources, and stakeholders	User-Centered Design; Working with Uncertainty; AI in Practice

The following section describes the research design and methods used to examine how students' curiosity, connections, and value creation evolved throughout the project.

4. Methodology

The study design leveraged both quantitative and qualitative data to answer the aforementioned research questions. The following sections detail the data sources and data coding schemes.

4.1 Participants

This study was conducted in Spring 2025 in a junior-level sensing course in Civil and Environmental Engineering at Carnegie Mellon University. The course, *Experimental & Sensing Systems Design and Computation for Infrastructure Systems*, enrolled 16 students, and used an IRB-exempt protocol to collect students' artifacts. Students were given an option to opt-out without any penalty. No compensation was provided. Data for this research were de-identified and analyzed after the semester ended. While there were 16 students in the class, the sample size varies for each analysis based on student completion of each corresponding assignment.

4.2 Data Sources

4.2.1 Pre-and post-survey measuring curiosity (RQ1)

Pre- and post-surveys provided direct evidence of how students' curiosity evolved over the course of the NZEB challenge-based project. Prior to and following the project, students completed a Google Form that included two items adapted from the Curiosity Direct Assessment developed by West et al. [27].

1. *Think about all the things you are curious about related to "Net Zero Energy Buildings". Take five minutes to write down anything that comes to mind in the text box.*
2. *Using what you wrote above, please write the top 10 questions you have about "Net Zero Energy Buildings".*

At the conclusion of the semester, the students' survey responses to item 2 above were de-identified, meaning both the student identity and whether the survey was pre or post was removed. The instructor then scored students' top 10 questions (representing curiosity) on a 6-point scale measuring cognitive depth (see Table 2). Curiosity was measured through the cognitive depth of student-generated questions. The "cognitive depth" scale was adapted from Bloom's Taxonomy [28] to illustrate how cognitive depth increases as one moves up the scale, with level 1, remembering, representing the most surface-level questions.

Table 2. Cognitive depth scale with examples for assessment of Curiosity

Cognitive Depth Level	Example Question
6. Creating (highest)	When designing a Net Zero Energy Building tailored to Pittsburgh Climate. What features would you include to achieve energy balance, and how would they interact to optimize performance?
5. Evaluating	Which NZEB design feature is most critical for achieving energy balance, and why?
4. Analyzing	What are the key components of a Net Zero Energy Building, and Net Zero how do they interact to reduce energy consumption?
3. Applying	How would you apply NZEB design principles to a school building to help it achieve Net Zero energy?
2. Understanding	How does a Net Zero Energy Building differ from a traditional building?
1. Remembering (lowest)	What is a Net Zero Energy Building?

4.2.2 Student reflections measuring connections (RQ2)

Guest speakers were intentionally incorporated to provide students with different perspectives on the field and to allow students to make connections outside of course material to Net Zero energy buildings. Guest speakers occurred during weeks 3, 4 and 5 modules (Investigate and Act). Following the week 4 and week 5 guest lectures, students completed a reflection in which they responded to the following prompts:

1. *What are some ideas from the guest lecture that you can use to advance your perspective of retrofitting approaches to get to Net Zero energy buildings?*
2. *What is an idea from the guest lecture that you might apply when working in your future career?*
3. *Describe at least two connections that you identify between engineering and concepts from other disciplines (e.g. thermodynamics, economics, chemistry, or humanities) when designing a Net Zero energy building.*

Reflections after the guest speaker sessions offered qualitative insight into the interdisciplinary connections students recognized as they engaged with real-world practical perspectives. As with the curiosity items, the students' reflection responses were similarly de-identified. The instructor then scored the reflections using the rubric below adapted from [29], consisting of the following dimensions: conceptual depth, application to career, interdisciplinary integration, personal relevance and systems thinking (Table 3).

Table 3. Criteria for Evaluating Connections in Students' Individual Reflections

Dimension	Indicators	Level 1: Emerging	Level 2: Developing	Level 3: Proficient	Level 4: Exemplary
Conceptual Depth	Understanding of retrofitting strategies and Net Zero principles	Mentions basic ideas with limited explanation	Describes concepts with some clarity; may lack nuance	Explains ideas clearly with thoughtful interpretation	Synthesizes ideas with deep insight and grows the original framing
Application to Career	Use of lecture ideas in future professional context	Vague or generic career link	Identifies a relevant idea but lacks specificity	Connects ideas to a specific role, challenge, or sector	Applies ideas with clear intent and personal relevance to future work
Interdisciplinary Integration	Connections between engineering and ≥2 disciplines	Mentions disciplines without clear linkage	Links disciplines with basic relevance	Explains how disciplines interact in design context	Demonstrates sophisticated integration across fields with clear impact
Personal Relevance	Engagement, values, or ethical reflection	Detached or impersonal response	Some personal engagement or ethical consideration	Reflects personal values or ethical stance with clarity	Deeply personal reflection showing growth, empathy, or transformation
Systems Thinking	Recognition of interdependencies (e.g., energy, economics, policy, behavior)	Fragmented or isolated ideas	Identifies some interdependencies	Explains system-level interactions with clarity	Demonstrates holistic understanding and anticipates ripple effects

4.2.3 Final group projects measuring creating value (RQ3)

To assess Creating Value, the final group project reports served as authentic artifacts demonstrating how students applied course concepts to create value for users, communities, or to meet broader societal needs. In the final report students are expected to expand on their earlier Building Envelope Efficiency report from week 3, potentially by integrating new insights from architecture, business, and policy frameworks. The assignment requires students to document their data collection methods, analyze their sensing data, and calculate baseline thermal-efficiency metrics, including EUI and the SCC, before interpreting their findings through principles of building physics. They then propose evidence-based recommendations to improve envelope performance by designing a higher-efficiency wall section, estimating changes in heat flux and energy consumption, and outlining three innovative retrofit options within the project budget. The report culminates in a value proposition that articulates the benefits, feasibility, and stakeholder relevance of the proposed solutions, supported by quantitative impacts and a concise summary of findings. As with the other outcomes, students' ability to demonstrate creating value was measured by applying rubric to de-identified student work. It should be noted that for this data source, students were working in teams rather than individually. The instructor applied a rubric (Table 4) adapted from [29] to measure creating value.

Table 4. Criteria for Evaluating Value Creation in Final Group Project Reports

	Emerging	Proficient	Advanced
Criteria	1	2	3
Value Proposition Development - stakeholder needs and motivations	Value proposition does not address stakeholder core needs AND does not demonstrate an understanding of stakeholder motivations	Value proposition addresses stakeholder core needs BUT does not fully demonstrate a deep understanding of stakeholder motivations	Value proposition addresses stakeholder core needs AND demonstrates a deep understanding of stakeholder motivations
Innovation in Idea/Design/Solution - impactful (ROI, Reduction in EUI, SCC)	1 of the proposed ideas is highly impactful	2 of the proposed ideas are highly impactful	3 of the ideas are highly impactful
Systems thinking approach - tied to EUI and SCC in a deep reasonable manner	attempts to relate to the systems thinking approach	clear ideas showing systems thinking approach	exceeded expectations for systems thinking approach
Innovation in Idea/Design/Solution - Applicable and aligned with Net Zero energy principles	1 of the proposed ideas has an alignment with the NZEB principles	2 of the proposed ideas have an alignment with the NZEB principles	3 of the proposed ideas have an alignment with the NZEB principles
Quantitative Evaluation - Accuracy of calculations	Provides basic or incomplete calculations (e.g., energy savings or ROI) with limited interpretation.	Accurately calculates, with clear assumptions and easy to follow calculations- and interprets SOME of the expected evaluation: energy savings, ROI, NPV, and stakeholder benefits using appropriate methods.	Accurately calculates, with clear assumptions and easy to follow calculations- and interprets ALL of the expected evaluation: energy savings, ROI, NPV, and stakeholder benefits using appropriate methods.
Societal Value/Stakeholder Considerations	Identifies general benefits (e.g., cost savings or sustainability) but lacks depth or evidence.	supported by credible sources. The case is supported by environmental, social, and productivity benefits to stakeholders.	Builds a persuasive, evidence-based business case integrating scholarly research, guest speaker insights, and quantifiable benefits.

5. Results

5. 1 Curiosity *(RQ1)*

After coding twelve students' top 10 questions about Net Zero energy buildings using the aforementioned procedure, each student received an overall composite score calculated by an average of all 10 question ratings and a researcher (not the coder) paired pre and post responses. A matched pairs analysis showed that students' mean score for cognitive depth at pre ($M=3.28$, $SD = 0.75$) was significantly lower than at post ($M=4.3$, $SD=0.52$) ($Z=-2.48$, $p=0.01$). This shift reflects that students' questions overall moved up a level of cognitive depth from applying to analyzing (Table 2). In total 240 questions were coded (120 from 12 students at pre and 120 from 12 students at post). The distribution of the ratings from pre to post can be found below (Figure 2) further highlighting the shift to asking more cognitively deep questions following the modules.

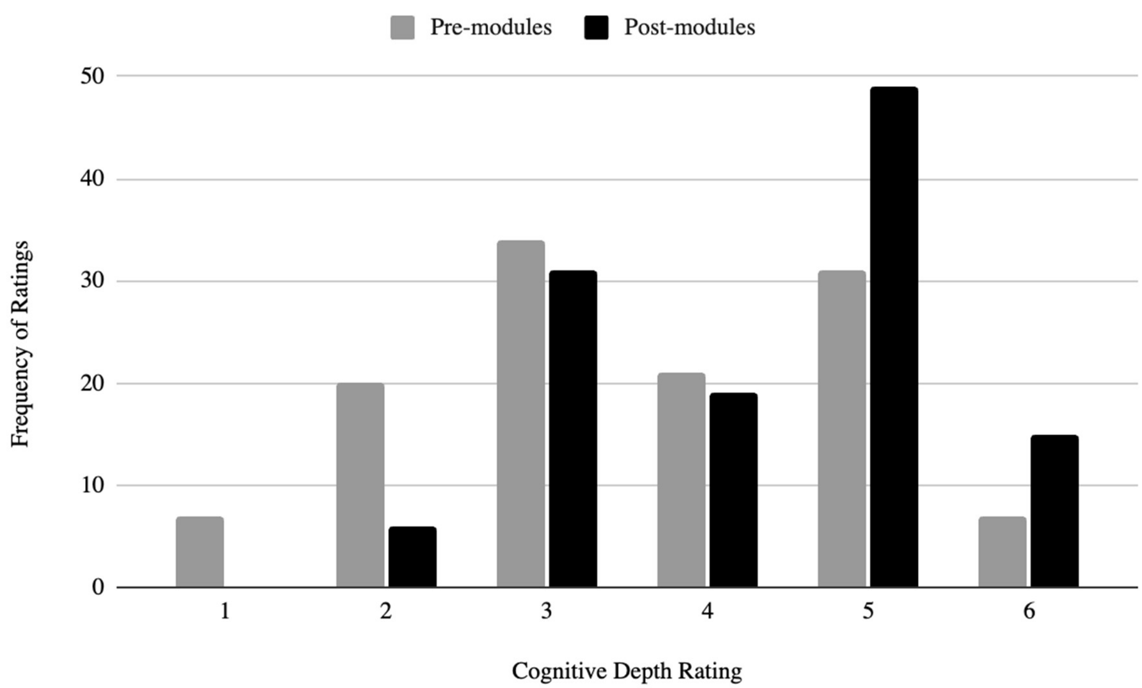

Figure 2. Distribution of cognitive depth ratings from pre- to post-survey

5.2 Connections *(RQ2)*

Analyzing reflections from sixteen students revealed that reflection scores increased across all rubric dimensions (Table 5). Additionally, a non-parametric matched pairs Wilcoxon signed rank test demonstrated that on average overall reflection scores for the second reflection ($M=3.10$, $SD=1.02$) were statistically significantly higher than for reflection 1 ($M=2.36$, $SD=0.82$) (Z=-

2.67, p=0.007). These findings suggest that students articulated more complex connections at the conclusion of the second guest-lecture reflection.

Students drew from a range of disciplines as they made sense of NZEB-related concepts, weaving together insights from thermodynamics, economics, chemistry, materials science, public policy, architecture and design, public health, psychology, communication, business, humanities, and politics. Across the two reflections, students demonstrated both continuity and expansion in the disciplines they drew upon. Several domains such as business/economics, communication, policy/politics, material science, air quality, design/architecture, chemistry, psychology, and humanities remained present in both reflection 1 and 2. Notably, thermodynamics, one of the strongest anchors in reflection 1 (11 references), dropped substantially in reflection 2 (6 references), suggesting that students may have relied less on core technical principles as the context or framing of the assignment shifted.

Connections to materials science and public health were mentioned in reflection 1, on the other hand, reflection 2 showed broader connections into new disciplines not previously mentioned in Reflection 1, including data science, health science, physics, general science, structural design, and urban planning. These additions suggest that students expanded their interdisciplinary thinking by incorporating more diverse analytical and applied perspectives.

Table 5. Mean student scores on connection rubric categories

	Mean (Scale 1-4)	
Categories	Reflection 1	Reflection 2
Conceptual Depth	2.31	3.25
Application to Career	2.50	3.19
Interdisciplinary Integration	2.31	3.25
Personal Relevance	2.69	2.94
Systems Thinking	2.00	2.88
Average	2.36	3.10

5.3 Creating *Value (RQ3)*

Analysis of students' final reports performance by using the rubric presented in Table 4 showed a variation in how teams translated technical NZEB analysis into a stakeholder-centered value proposition (see Table 6). There was a total of four student teams. Team A performed strongest across stakeholder needs and motivations, innovation for ideas presented, idea alignment with the NZEB principles, and societal considerations, indicating a well-rounded approach that combined persuasive stakeholder framing with high-impact ideas supported by credible sources. Their quantitative work was proficient (2/3) but their systems thinking score (1/3) signaled a missed opportunity to explicitly link building-level retrofitting ideas to the whole-building EUI and SCC savings. Team B produced consistently proficient work across most criteria, although they did not reach the advanced tier, they demonstrated the best use of the IR images they included demonstrating reliable value proposition with 11 credible citations and reasonable systems thinking. Team C scored lowest overall, with limited stakeholder insight, few high-impact ideas due to choosing a relatively new building with no visible thermal leak issues, and weak quantitative evidence; however, their consistent score of 3 on societal value suggests they recognized broad benefits even if they could not substantiate them. Team D shows a mixed profile; they have used the highest number of credible sources in their final report (16) and demonstrated advanced stakeholder framing but weaker quantitative rigor, innovation in ideas, and only moderate systems thinking.

Table 6. Value Proposition Assessment Scores for team final project reports

	Team			
Criteria	A	B	C	D
Value Proposition Development - stakeholder needs and motivations	3	2	1	2
Innovation in Idea/Design/Solution - impactful (ROI, Reduction in EUI, SCC)	3	2	1	2
systems thinking approach - tied to EUI and SCC in a deep reasonable manner	1	2	1	2
Innovation in Idea/Design/Solution - Applicable and aligned with Net Zero energy principles	3	2	2	2
Quantitative Evaluation - Accuracy of calculations	2	2	1	1
Societal Value/Stakeholder Considerations	3	3	3	3

6. Discussion

Embedding EM within a technically rigorous sensing laboratory was associated with measurable growth in curiosity and interdisciplinary integration. Students progressed from procedural inquiry toward analytical and system-oriented questioning, and reflective writing demonstrated broader socio-technical integration over time.

The increase in cognitive depth suggests that authentic sensing tasks anchored in real institutional goals can stimulate exploratory reasoning beyond technical compliance. Similarly, exposure to interdisciplinary guest experts and real-world constraints appeared to scaffold systems thinking, expanding student reasoning beyond thermodynamics into economics, policy, public health, and urban planning.

Final project variation revealed uneven integration of quantitative systems impacts. While several teams demonstrated strong stakeholder framing and persuasive value propositions, explicit linkage between retrofit recommendations and whole-building EUI and SCC impacts was uneven. This indicates that while students can develop compelling narratives of value, deliberate instructional scaffolds may be needed to strengthen quantitative systems integration. Future iterations of the project may incorporate structured checkpoints focused specifically on tracing building-level interventions to measurable system-wide outcomes.

Three instructional design implications emerge from this study:

1. Sequence technical rigor before systems expansion: Establishing strong technical foundations in sensing and uncertainty allowed students to later integrate broader economic and policy dimensions without sacrificing analytical depth.

2. Embed stakeholder accountability within technical tasks: Requiring students to present to facilities representatives and practitioners increased authenticity and motivated more careful justification of claims.

3. Assess mindset through authentic artifacts: Measuring curiosity through question depth, connections through structured reflection, and value creation through project deliverables provided aligned and observable evidence of mindset development.

Importantly, this work positions EM as the cognitive engine through which students enact the future-oriented technical competencies identified by the ASCE. Curiosity supported rigorous data interrogation, Connections enabled interdisciplinary integration, and Creating Value drove stakeholder-centered decision-making. Rather than competing frameworks, EM and ASCE competencies appear mutually reinforcing when intentionally aligned through instructional design.

Limitations and Future Work

This study is limited by its small sample size, single-course context, and absence of a control group. Although rubrics were applied systematically, some degree of subjectivity remains in evaluating cognitive depth and interdisciplinary integration. Future research should incorporate interrater reliability, expand across institutions, and examine long-term persistence of EM Habits of Mind beyond a single semester. Additional work could also explore how structured quantitative scaffolds influence the strength of systems-level reasoning in final value propositions.

7. Conclusion

This study examined a six-week NZEB sensing module intentionally designed to align with both the ASCE Technical skills and the KEEN EM framework within a junior-level civil engineering laboratory. Students demonstrated growth in cognitive depth, interdisciplinary integration, and stakeholder-informed value propositions, suggesting that EM can be embedded and cultivated within core technical coursework without sacrificing analytical rigor. Integrating technical competence with habits of inquiry, integration, and value-driven action is essential for preparing civil engineers to address decarbonization and infrastructure resilience. When intentionally aligned, mindset and technical depth reinforce one another in complex socio-technical contexts.

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