Cultivating Entrepreneurial Mindset Through Simulation-Based Sustainable Design

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Cultivating the Entrepreneurial Mindset through Sustainable Housing Design

Abstract

Preparing engineering students to address sustainability challenges requires more than technical proficiency; it requires cultivating an entrepreneurial mindset (EM). The EM, characterized by curiosity, connections, and creating value, equips students to question assumptions, integrate diverse forms of knowledge, and design solutions that generate societal and economic impact. Embedding this mindset into design-based coursework allows students to practice not only solving technical problems but also framing them as opportunities for innovation and value creation. In this study, undergraduate students engaged in a sustainable housing design challenge using *Aladdin*, a cloud-based simulation platform for energy-efficient buildings. The task required designing an energy-efficient home for a hypothetical client in Midwest, under constraints of size, accessibility, curb appeal, and energy efficiency. Students submitted final house models and written reflections explaining how their designs achieved sustainability goals from the economic, environmental, and social perspectives. We analyzed 25 reflections qualitatively using the KEEN 3Cs framework. The analysis revealed distinct patterns in how EM was expressed. Curiosity emerged when students confronted trade-offs in their design, leading them to probe constraints, test alternatives, and iterate. For example, conflicts between aesthetics and efficiency, or unexpected simulation outputs, prompted deeper questioning and exploration. Connections were the most consistent feature, with students linking energy-efficiency performance, size, and solar orientation into coherent system-level rationales. Though most reasoning was linear, students demonstrated increasing ability to integrate across subsystems and contexts. Creating Value appeared when students explicitly considered stakeholders' perspectives alongside their own as an engineer, as well as communities and the environment. Here, reflections addressed environmental stability based on their reliance on solar energy, insulation, and strategic design, situating technical choices within broader socio-technical systems. Findings suggest that constraint-driven, open-ended design activities can effectively surface all three dimensions of entrepreneurial thinking. By embedding simulation-based design challenges that spark curiosity, requiring system integration to highlight connections, and framing design tasks around real clients and communities to emphasize value creation. Educators can leverage simulation-based challenges to foster an entrepreneurial mindset alongside technical learning. Future work should further operationalize EM assessment by pairing reflections with process data and exploring feedback mechanisms that guide students toward deeper connections and explicit value articulation.

Keywords: Entrepreneurial Mindset, Sustainable Housing Design, Curiosity, Connections, Creating Value

Background

Engineering education has traditionally emphasized technical mastery, efficiency, and problem-solving under well-defined constraints [1]. While these competencies remain essential, the rapidly changing technological and societal landscape now demands that engineers also demonstrate creativity, adaptability, and purpose-driven thinking[2]. Engineers are increasingly expected to address complex, open-ended problems such as climate resilience, sustainable infrastructure, and equitable technology access that extend far beyond disciplinary boundaries [3], [4]. These global challenges require more than technical skill; they require a mindset oriented toward innovation, systems understanding, and social responsibility. In response to this evolving landscape, the entrepreneurial mindset (EM) has emerged as a transformative educational framework in engineering [5]. EM encourages learners to approach problems with curiosity, to connect knowledge across diverse contexts, and to create value that benefits both individuals and communities [5]. It shifts the focus from producing technically correct solutions to developing engineers who can identify opportunities, frame challenges creatively, and generate impact through their designs [6]. By fostering EM, educators aim to prepare graduates who can thrive in uncertainty, lead interdisciplinary teams, and contribute to sustainable innovation [6]. The need for EM in engineering education is further reinforced by industry and accreditation bodies emphasizing the development of professional skills such as innovation, ethical reasoning, teamwork, and communication [7]. Employers increasingly seek graduates who can navigate ambiguity, engage stakeholders, and translate ideas into implementable solutions. EM thus serves as a bridge between academic learning and real-world engineering practice [8], equipping students with both the technical foundation and the mindset required for lifelong learning and societal contribution.

In educational practice, EM is most effectively cultivated through experiential and project-based learning environments where students apply concepts in authentic contexts. Project-based learning (PBL), in particular, positions students as self-directed learners who investigate and solve complex, real-world problems and is well aligned with the entrepreneurial mindset's emphasis on curiosity, connections, and creating value. Vignola et al. [9] demonstrate how PBL can effectively integrate the 3Cs of EM even within a traditionally math-intensive engineering statistics course. Their sequence of four mini-projects encouraged students to explore personal interests, make interdisciplinary connections, and communicate the value of statistics through creative artifacts such as YouTube videos, robotics demonstrations, and simulations of "a world without statistics." By situating learning in authentic contexts, including public presentations at an Innovation Showcase, the authors illustrate how PBL supports students in investigating ideas independently (curiosity), synthesizing knowledge across domains (connections), and articulating the societal relevance of technical content (creating value). Sustainability-focused design projects provide particularly fertile ground for cultivating the entrepreneurial mindset because they require students to grapple with interconnected environmental, social, and economic dimensions while creating viable solutions. Education for sustainable development literature emphasizes that such contexts foster systems thinking, value-oriented reasoning, and strategic decision-making as students address real-world sustainability challenges [10], [11]. Sustainable entrepreneurship education further highlights how engaging students with sustainability problems can develop competencies such as opportunity recognition, critical thinking, collaboration, and creativity [12], [13]. Kotla and Bosman [14] demonstrate how entrepreneurially minded learning can be intentionally integrated into a virtual sustainability summer school by combining renewable-energy projects with design thinking, customer discovery, and elevator pitches. Grounded in Bosman and Fernhaber's [8] four intentions for cultivating the entrepreneurial mindset, they are- contextualized classrooms, professional skill development, opportunities to practice/reflect/receive feedback, and backward course design their curriculum enabled multidisciplinary, international teams to work on solar-energy challenges, build systems-thinking skills, and articulate value propositions for community stakeholders. Taken together, these studies suggest that sustainability-centered, entrepreneurially oriented projects inherently demand curiosity to explore alternatives, integrative thinking to understand system interactions, and a value orientation that keeps social and environmental relevance in focus.

Despite increasing recognition of the entrepreneurial mindset as a key outcome of sustainability and entrepreneurship education and growing guidance on curriculum frameworks, virtual collaboration, and culturally responsive teaching in this space [8], [11], [14] questions remain about how EM actually manifests in students' own reasoning during authentic design tasks. Existing work often foregrounds program design, reported learning outcomes, or thematic summaries of student perceptions, but provides fewer fine-grained accounts of how curiosity, systems integration, and value creation are *expressed* in students' reflective writing as they navigate concrete sustainability-driven design decisions. Examining how learners describe uncertainty, justify tradeoffs, and connect technical choices to broader social or environmental purposes can yield deeper insight into the development of EM within real design processes. Accordingly, this study analyzes student reflections from a sustainability-centered, energy-efficient housing design activity to examine how the entrepreneurial mindset is articulated through their thinking and decision-making. The research question that we plan to answer through this study is: *how can students' reflections be characterized in terms of the evidence they provide for the entrepreneurial mindset as they engage in a sustainability-centered energy-efficient housing design activity?*

Theoretical Framework: The Three Cs of the Entrepreneurial Mindset

The entrepreneurial mindset (EM) offers a useful lens for understanding how engineering students think and act in uncertain, real-world contexts. Developed through initiatives such as KEEN, the framework highlights three dimensions: *curiosity, connections, and creating value* that inform this study's analysis of student reflections. Curiosity involves a willingness to ask questions, challenge assumptions, and explore beyond what is required. In engineering settings, it supports adaptive expertise and deeper conceptual understanding, especially when learners engage in open-ended design and reflection. *Connections* refer to integrating knowledge across disciplines and recognizing how technical decisions interact with broader physical, social, and environmental systems. This systems-oriented thinking enables students to link theory to practice and understand their designs within a larger context. *Creating Value* emphasizes aligning technical work with meaningful outcomes for stakeholders, communities, or society. Students demonstrate this when they justify design choices based on usability, sustainability, or long-term impact. Together, the three Cs position EM as both a cognitive and ethical orientation to engineering practice. This framework guides our examination of how students articulated these dimensions during a sustainability-focused energy-efficient housing design activity.

Methods

Research Design

This study employed a qualitative design to explore how the entrepreneurial mindset (EM) emerged in students' reflections during a sustainability-centered design activity. Guided by interpretive and constructivist traditions, the research sought to characterize how learners expressed curiosity, systems-oriented connections, and value creation in their written reflections. A qualitative approach was appropriate because it enabled close examination of students' meaning-making processes and the contextual nuances underlying their reasoning.

Context and Participants

The study was conducted in an undergraduate engineering course focused on sustainable system design and systems thinking at a large Midwestern university. As part of a required course module, students engaged in an energy-efficient housing design activity that required them to design an energy-efficient house at least capable of producing as much energy as it consumed annually. The task was implemented through a digital simulation platform called Aladdin that allowed students to work with design parameters such as building orientation, insulation, window placement, and solar panel configuration [15].

Participants included 25 undergraduate students enrolled in the course. Most were third- or fourth-year students majoring in mechanical, civil, or other engineering disciplines. Participation in the reflection activity was part of the course requirement, but students were informed that their responses could be analyzed for research purposes, and only de-identified data were used for this study. Institutional review board approval was obtained prior to data collection.

Data Collection

At the conclusion of the design activity, students completed a written reflection prompt asking them to explain their reasoning using the DSRP framework of systems thinking [16]with four elements: Distinctions, Systems, Relationships, and Perspectives. This prompt encouraged students to articulate how they conceptualized subsystems, recognized interdependencies, and considered multiple viewpoints while designing a sustainable house (see Figure 1). Student reflections included their responses to their reasoning about how they designed their houses the way they did, whether they used systems thinking, and how they reflected that into their engineering design challenges. They were also asked to look at the house as a system of systems and identify the subsystems within that system. Finally, they were asked to explain how their house is environmentally, economically, and socially sustainable and how they reflected that into their energy-efficient housing design.

Figure 1: **Example of an Energy-Efficient House Designed by a Study Participant**

Data Analysis

Data were analyzed thematically using a hybrid deductive–inductive approach [17], [18]. The deductive framework drew on the three Cs of the entrepreneurial mindset: curiosity, connections, and creating value as analytical lenses. Initially, all reflections were coded independently for evidence of these three constructs. The coding scheme included behavioral indicators such as questioning assumptions, identifying system interrelations, or referencing stakeholder benefits. During the second cycle of analysis, inductive coding captured emergent subthemes within each category, highlighting how students enacted EM in context. Representative quotes were extracted to illustrate key patterns and variations. To ensure trustworthiness, two researchers independently coded a subset of reflections and discussed discrepancies to reach consensus on code definitions and boundaries. Iterative memo writing and peer debriefing further supported analytical rigor.

Researcher Positionality

The researchers were instructors and education researchers with expertise in engineering education, systems thinking, and design pedagogy. Reflexive journaling was used to remain aware of potential biases in interpreting student reflections. Overall, this methodological approach allowed for a nuanced characterization of how the entrepreneurial mindset manifested in students' written reflections as they engaged in a sustainability-centered energy-efficient housing design experience.

Results

Curiosity, connections, and value creation were salient across student reflections on the energy-efficient housing design task. Below, we characterize how each 3C emerged, supported directly by student accounts.

Curiosity: Probing Constraints, Testing Alternatives, and Investigating Anomalies

Curiosity manifested as iterative experimentation, attention to trade-offs, and interrogation of the modeling environment. Several students described systematically refining their designs when changes improved one subsystem while harming another. One student noted:

"Through trial-and-error, I realized that some design choices had very positive effects on one subsystem while drastically decreasing the efficiency of another. Due to this, I had to find a balance between certain characteristics that allowed me to have a home that was both aesthetically pleasing but functioned year-round. For example, I had to decrease the size of my sun-facing window and the height of my shed to improve cooling efficiency in the hotter months."

Curiosity also extended to questioning the behavior and accuracy of the tool itself. For example:

"One thing I would like to note before beginning this question is that my house (per the math I did) is way less than the square footage listed on the website. I think the error likely stems from the unusual shape I made."

Students leveraged prior physics knowledge to test and justify design choices. As one reflection explains:

"More heat will be lost from a home through a larger window than through a smaller window of the same composition and thickness. … More heat will also be gained in a home through a larger window than a smaller window. … 'Albedo is 0 for a perfectly black surface (black surface absorbs maximum solar radiation).' This influenced my design of having all black roofing."

Curiosity was further evident in perspective-shifting, particularly through temporal and spatial exploration of solar paths:

"The line of sunlight was a great example of perspective in this assignment. We could use the tools to see where the sun would be pointing at a given time during the day, which would affect the solar energy created. A different perspective could be shown if we then switched the date to a time in the winter as opposed to a date in the summer. The challenge was finding the correct placement to maximize all of these opportunities for energy."

Collectively, these reflections indicate that when constraints and anomalies were visible, students engaged in purposeful questioning and iterative refinement consistent with an entrepreneurial, curiosity-driven mindset.

Connections: Linking Systems, Interdependencies, and Context

Connections emerged as the most pervasive theme. Students frequently framed their designs as interdependent systems involving envelope performance, mechanical loads, solar generation, storage, site conditions, and user needs.

Several reflections highlighted subsystem integration. One student emphasized coordinated decisions across heating, cooling, and generation:

“When designing my home, I focused on three primary subsystems: heating, cooling, and energy generation. … Placing all 40 of my solar panels and a heliostat on the sun-facing side of the house maximized my system’s energy production. … Implementing two batteries conserved a large amount of energy, especially during the transition between seasons.”

Others articulated explicit coupling between energy production and demand:

“The relationship between the solar panels and the energy consumption ensures that the house remains energy-efficient throughout the year. The opacity, R-values, and U-values of walls and the roof thickness work together to minimize heat loss. The solar water heaters reduce dependency on electrical heating, directly lowering energy demand.”

Students also recognized ecological and spatial trade-offs at the site level:

“I identified the relationship between the trees and the house, noting that trees may provide shade to the house, preventing additional A/C from being required, but also block solar energy from being able to be generated.”

Structural–energy interdependencies were described in terms of geometry, insulation, and performance:

“The efficiency of the solar panels depends on the angle of the roof and the amount of sunlight received, which in turn affects the overall energy efficiency of the house. The performance of the HVAC system is linked to the insulation values of the ceiling, walls, and roof, ensuring that heating and cooling needs are minimized.”

Students distinguished and coordinated active and passive strategies:

“I also wanted to distinguish between active and passive systems that contribute to energy usage throughout the year. Regarding this, I am referring to passive components like insulation and the number of windows, and their grade. The active component I was mainly considering was an HVAC system that would have to heat or cool the house if it was not insulated correctly.”

However, most connections remained linear (e.g., “more windows → more heat loss” or “more panels → more energy”). Few reflections explicitly articulated feedback loops or time-evolving dynamics (e.g., how storage, seasonal variation, and peak loads recursively shape design decisions).

Creating Value: Centering Stakeholders, Equity, Cost, and Carbon

Creating value surfaced in reflections that situated technical decisions within stakeholder needs, long-term affordability, environmental impact, and inclusion.

Some students explicitly integrated multiple stakeholder perspectives:

“From Sophia’s perspective, the design meets her goals of environmental consciousness, energy efficiency, and sustainability. The house is also visually appealing with a layout that accommodates both functionality and aesthetics. From an engineering perspective, the design balances practicality and sustainability by integrating passive energy-saving strategies as well as active renewable energy generation. Additionally, the design considers accessibility for diverse users, ensuring the house is inclusive.”

Others framed their designs through a triple-bottom-line lens:

“From an engineering perspective, the house is optimized for thermal efficiency and energy independence. From an economic perspective, solar panels and high-quality insulation reduce long-term electricity and heating costs. From an environmental perspective, the house minimizes carbon emissions, while the inclusion of native trees enhances air quality and biodiversity. From a social perspective, accessibility features (such as wide doorways and step-free entryways) ensure inclusivity for people with disabilities and older residents.”

Students also explicitly acknowledged design trade-offs in service of value:

“Using a design perspective, I valued including many windows to make a more aesthetic home at the expense of more heat loss during cold winter months. However, using a sustainability perspective, I valued the lack of heat loss during winter months at the expense of fewer windows and worse aesthetics.” (Student 5)

And in some cases, they considered neighborhood-level fit:

“For the people of [city name], it must be aesthetically pleasing, and fitting into the neighborhood it will be built.”

While many students articulated why their choices mattered for users, communities, and the environment, value claims were predominantly qualitative; quantitative indicators (e.g., lifecycle cost, comfort hours, carbon reduction, accessibility metrics) were rarely provided.

Overall 3C Profile of the Activity

Taken together, the reflections suggest that the energy-efficient housing design task effectively elicited key dimensions of the 3Cs:

- curiosity was activated when constraints and anomalies surfaced, prompting targeted experimentation and model interrogation.
- connections were frequently made across subsystems, disciplines, and scales, though typically as one-way relationships rather than closed feedback loops.
- creating value emerged when students framed decisions in relation to specific stakeholders and societal outcomes, with clear but mostly qualitative attention to environmental and social responsibility.

These patterns indicate that the activity supports foundational entrepreneurial mindset outcomes, while also highlighting opportunities to scaffold feedback-loop reasoning and quantitative value analysis in future implementations.

Discussion

The findings highlight how an energy-efficient housing design task can serve as a powerful environment for cultivating entrepreneurial mindset attributes within engineering education. Students' reflections demonstrated the development of curiosity, systems-oriented connections, and a growing awareness of value creation each emerging naturally from authentic engagement with design complexity. Rather than functioning as isolated competencies, these three dimensions appeared intertwined, suggesting that curiosity fueled systems exploration, while systems understanding grounded students' ability to articulate meaningful value propositions. Curiosity was primarily triggered by design tensions and anomalies, showcasing the pedagogical importance of structured friction in problem framing [19]. When students encountered conflicting goals such as aesthetics versus efficiency, they engaged in iterative reasoning rather than converging prematurely on a single solution. This aligns with prior studies emphasizing that productive uncertainty can act as a catalyst for deep learning and adaptive expertise [20], [21], [22]. Designing tasks that intentionally surface competing constraints may therefore be more effective for fostering inquiry-driven habits of mind than highly structured or purely analytical exercises. The connections students drew across subsystems, materials, and contextual variables showcase a shift from component-level optimization toward systems integration. This systems perspective reflects early-stage systems thinking competence, where learners recognize interdependencies but have yet to model feedback or dynamic interactions [23], [24]. To deepen this capacity, future iterations of the activity could incorporate simple modeling tools such as causal loop diagrams or energy flow maps to make invisible feedback visible. Embedding quantitative reasoning alongside conceptual connections would strengthen learners' ability to move from intuitive pattern recognition to analytical prediction, an essential step in engineering design education. Reflections on creating value indicate that many students are beginning to internalize a stakeholder-oriented design mindset. They linked engineering decisions not only to technical performance but also to accessibility, community aesthetics, and environmental sustainability. However, the predominance of qualitative reasoning suggests that value creation remains an interpretive exercise rather than an evidence-based one. Introducing methods such as simplified cost-benefit analyses, carbon accounting, or comfort metrics could help operationalize value and bridge ethical intentions with measurable impact [25], [26], [27]. Overall, the study showcases that when students engage in authentic, open-ended design problems that integrate sustainability constraints, they naturally enact the three C's of curiosity, connection, and value creation. The pedagogical challenge and opportunity lie in helping learners translate these intuitive behaviors into explicit, transferable competencies for professional engineering practice.

Implications for Educators

The findings suggest several ways educators can design learning experiences that foster curiosity, systems thinking, and value creation. First, instructors can use structured friction, creating tasks with competing goals such as cost versus sustainability to spark curiosity. When students face tensions and document their "surprises," they learn to question assumptions and iterate with purpose. Second, educators can strengthen systems thinking by helping students see interconnections. Simple tools like causal loop diagrams or flow maps can make cause-and-effect relationships visible and promote reasoning about change across subsystems. Asking learners to explain how one decision influences another encourages deeper understanding of system dynamics. Third, to promote value creation, educators can guide students to connect design choices with measurable impacts. Short exercises such as estimating payback time, energy balance, or comfort metrics help students move from abstract values to evidence-based reasoning. A short summary that identifies key stakeholders, the benefits they receive, and one metric for each can make this thinking explicit. Finally, reflection should be treated as an ongoing habit rather than a final step. Structured prompts and peer discussions can help students connect curiosity, systems awareness, and value creation as part of their design reasoning.

Together, these practices encourage learners to engage with uncertainty, think across systems, and consider human and environmental impact, key capacities for sustainable and responsible engineering practice.

Conclusion, Limitations, and Future Work

This study illustrates how sustainability-focused design experiences can nurture curiosity, systems thinking, and value creation among engineering students. The activity encouraged students to think beyond technical optimization and to connect design choices with environmental and social contexts. Overall, it demonstrates the potential of experiential learning to advance integrative and reflective engineering practice. Several limitations should be noted. The study relied on self-reported reflections from a single course, which limits the ability to generalize findings or observe design behaviors directly. The reflections also emphasized qualitative reasoning, offering limited evidence of quantitative or data-driven analysis. Future research should expand data sources to include design artifacts, performance metrics, and peer collaboration records to provide a more complete view of learning. Longitudinal studies could trace how curiosity, systems awareness, and value orientation develop across multiple design experiences. Further, integrating scaffolded modeling tools or stakeholder engagement may help students translate these insights into measurable design outcomes. Overall, sustainability-centered design tasks show promise for developing reflective and responsible engineers equipped to navigate complex, real-world challenges.

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