

The Manifestations of Conscientious Design in the Context of a Sustainable Engineering Project in Hawai'i*

AUSTIN MORGAN KAINOA PETERS¹, JIWON KIM¹, SENAY PURZER¹, AARON HANAII² and CHARLES XIE³

¹School of Engineering Education, Purdue University, West Lafayette, IN 49707, USA.

E-mail (in order of authorship): peter791@purdue.edu, jwkim@purdue.edu, purzer@purdue.edu

²Department of Math and Sciences, Kapi'olani Community College, Honolulu, HI 96816, USA. E-mail: hanaia@hawaii.edu

³Institute for Future Intelligence, Natick, MA 01760, USA. E-mail: charles@intofuture.org

This article introduces a new approach to design called conscientious design that promotes and elicits the transformative agency of designers through the conscientious negotiation of risk and benefits. We argue that an emphasis on transformative agency can help designers enact their individualized knowledges, experiences, and values throughout the design process to move towards collective social change. However, an important aspect of bringing about transformative agency through design is to articulate the conscientious negotiation of design decisions through reasoning fluency. In this study, we demonstrate the ways that reasoning fluency promotes transformative agency through college students' design posters situated in a course project to design solar panel installations to help Hawai'i reach carbon neutrality. A qualitative hermeneutic inquiry resulted in five increasingly conscientious levels of design reasoning, ranging from technological determinism as an inhibitor to reasoning fluency to multicultural ingenuity and ethical integrity as promoters of transformative agency. Our findings demonstrate how design can be individually shaped and socially transformed through a conscientious design approach.

Keywords: conscientious design; transformative agency; design reasoning

1. Introduction

The understanding of how designers think, reason, and act is a prominent research topic that produced critical insights over the years [1]. With the recent developments and popularity of artificial intelligence (AI) in the design space, it is even more vital to cultivate conscientious awareness and ethical responsibility of designers to reflect on and justify the potential risks and benefits of their design decisions, including the use of AI technology [2].

Previously, focusing on users and clients situated humans as a core element of good design [3, 4]. However, in recent years, these design practices have been scrutinized for their shortcomings, such as racial biases that perpetuate discrimination [5] as well as an overreliance on end users that may not have the tacit knowledge to understand the full impact of the design, that may limit design creativity, and that may represent only a subset of the actual people and environments that the design affects [6].

We argue that there are several potential inter-related reasons for these shortcomings. First, the prior representations of design processes have underemphasized the ethical responsibilities of the designers [7]. These design processes emphasize actions and iteration but not the essential introspective practice and articulation of negotiations where designers bring in their individual back-

grounds and expertise from multiple disciplines to weigh trade-offs and consequences of different design decisions. Second is the difficulty of fluently balancing and integrating technical depth and multidisciplinary breadth in the articulation of design reasoning that comes with these negotiations. Third, despite rich research on designer agency [8, 9] that is at the center of these negotiations, it is not clear how this agency can be promoted among learners. There is a need for a design framework that promotes students' transformative agency as a way to support them in articulating and justifying these negotiations.

Our understanding of transformative agency situates learners as agents of change [10] and provides them the space to bring in their full selves to enact these changes. Due to design's open-ended nature [11] with a wide range of technical, social, cultural, and environmental effects, design can be a transformative activity when designers bring in their individual knowledges, experiences, and values to move towards a just and sustainable future [12]. Our approach to design centers on the importance of designers' transformative agency in addressing the previously described needs and shortcomings. We are calling this new concept *conscientious design* that situates the design process as a constant negotiation of risks and benefits that informs design decisions. Through conscientious design, designers explicitly and fre-

quently articulate many consequences and possibilities that come with their design decisions to better recognize and act on the rationale needed to justify their decisions.

The goal of this paper is threefold: (1) to introduce the conscientious design framework; (2) identify the manifestations of conscientious design in students' design discourse in an AI-enabled solar design project; and (3) provide recommendations for the conscientious design framework that centers a designer's transformative energy.

2. Background – Agency and Design

Our understanding of agency begins with Emirbayer and Mische's [13] triad of agency (iteration, projectivity, and practical evaluation), which respectively represents bringing in previous experiences into current practice, imagining possible futures, and making judgements based on changing and competing demands. The design process as an evidence-based decision-making process situated in the individual synthesizing and thinking through the evolution and impacts of their design [11] directly aligns with this theory of agency. Similarly, the open-endedness and uncertainty [8, 11] of the design process creates spaces for designers to enact their agency, illustrating how design is a performance of agency to reconfigure an evolving world [9].

Transformative agency in design is accomplished through positioning people as agents in their own communities and realities to help make collective social change [14], meaning that the ways that people enact transformative agency look differently for each person. Design work and design education also represent an area that has many opportunities for designers to enact their transformative agency through having purposeful and authentic problems that allow designers to bring in their multiple lenses [11] and promote a multiplicity of ideas towards collective action [14, 15]. Transformative agency is important in engineering and engineering education, as this concept facilitates how the technical aspects of engineering work together with societal, environmental, and cultural aspects. Research on how to achieve transformative agency is new but growing. In engineering industry, practitioners use transformative agency to create new ideas and organizational systems in their work environments [16] and in engineering education, students in makerspaces used their transformative agency to move beyond the initial design requirements towards solutions that align with their backgrounds [17]. There is, however, research on the historical and cultural foundations of engineering and engineering education that oppose transformative agency.

In engineering education, Gelles and colleagues [18] illustrate how engineering students defaulted to efficiency in their energy course to resolve environmental degradation in the energy sector. Students viewed a technical answer of efficiency as the way out of the crisis while neglecting social and environmental impacts. Vanasupa and colleagues [19] offer a possible explanation for how a prioritization of the technical is built into the foundation of engineering industry. They describe how American engineering is a field developed during the Industrial Revolution leading to a valuing of Western industrialized concepts like efficiency, neutrality, and uniformity. These values are inherently related to the technical aspects of engineering work and exacerbate how engineering curriculum and engineering students understand engineering work, including design work, as neutral and apolitical [20].

Valuing the neutral and depoliticized technical aspects of engineering represents a larger manifestation of Western engineering and engineering education valuing the myth of objectivity [20–22]. Riley [21] explains that believing in the myth of objectivity perpetuates reductionist and technological deterministic perspectives in the engineering design process, which helps position the designer as an unbiased subject and designs as neutral. From this unbiased mindset, the designer can ignore the political, cultural, and economic impacts of their designs, despite ABET student outcome criterion 3.2 calling for “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors” [23]. An objective mindset built into the cultural foundation of engineering and engineering education stands in opposition to the multiple frames of references and plurality necessary in both transformative agency and design [11, 15]. If objectivity through the reliance on technical aspects is built into the larger cultural and historical foundation of engineering and engineering education, how do we promote transformative agency towards better design?

3. Conscientious Design Framework

Conscientious design is a deliberate re-centering of engineering design practice towards a holistic negotiation of risks and benefits, so engineering solutions are not just effective and efficient but positively transformative for communities today and in the future. Engineering is inherently a socio-technical profession at the intersection of people, technology, environment, and resources. Hence, design in such a sociotechnical context requires an

intentional centering of a conscientious negotiation fueled with experiential knowledge, the balancing of trade-offs, first-principles logic, and thinking about probable futures. Conscientious design requires reasoning fluency because reasoning alone is not sufficient. To enact student designers' transformative agency and achieve positive transformative change, reasoning must be catalyzed with multicultural ingenuity and ethical integrity [24].

The conscientious design framework does not prescribe a specific design process but rather emphasizes internal and external reflection and negotiation throughout any design process. This conscientious negotiation occurs when students engage in design projects where they are presented with purposeful and authentic choices that create opportunities for pluralism and the need for designers to examine their reasoning. Thus, a purposeful and authentic design project is two important aspects of conscientious design [25]. After the structure of the project, there are three critical ingredients needed for designers to bring about conscientious design through negotiation: reasoning fluency, multicultural ingenuity, and ethical integrity. These three aspects represent the ways that students enact the conscientious design framework and consequently transformative agency in their design work.

Reasoning fluency occurs across four reasoning quadrants depicted in Fig. 1. These four quadrants are created at the intersection of two semantic axes:

semantic gravity and semantic density (See [24, 26] for more details). Semantic gravity represents contextualized meaning, which is weaker in theoretical, abstracted contexts (SG-) and stronger in practical, contextualized contexts (SG+). Semantic density represents complexity of meanings, where higher density represents multi-disciplinary breath (SD+) and lower density represents disciplinary depth (SD-).

Each reasoning quadrant represents different types of knowledges and associated reasonings essential for engineering design decisions. The four reasoning quadrants are:

- *Experiential Reasoning*: Understanding of contexts using experiential learning, cultural perspectives, prior knowledge, and prior experiences.
- *First-Principles Reasoning*: Understanding of disciplinary core ideas, also known as disciplinary depth.
- *Trade-offs Reasoning*: Understanding of competing design requirements and assumptions, including multi-disciplinary breadth.
- *Futures Reasoning*: Understanding of multiple possible futures created through design, including intended and unintended consequences of such design with respect to changing time and context.

For this study on transformative agency, we focus on how students move across the reasoning

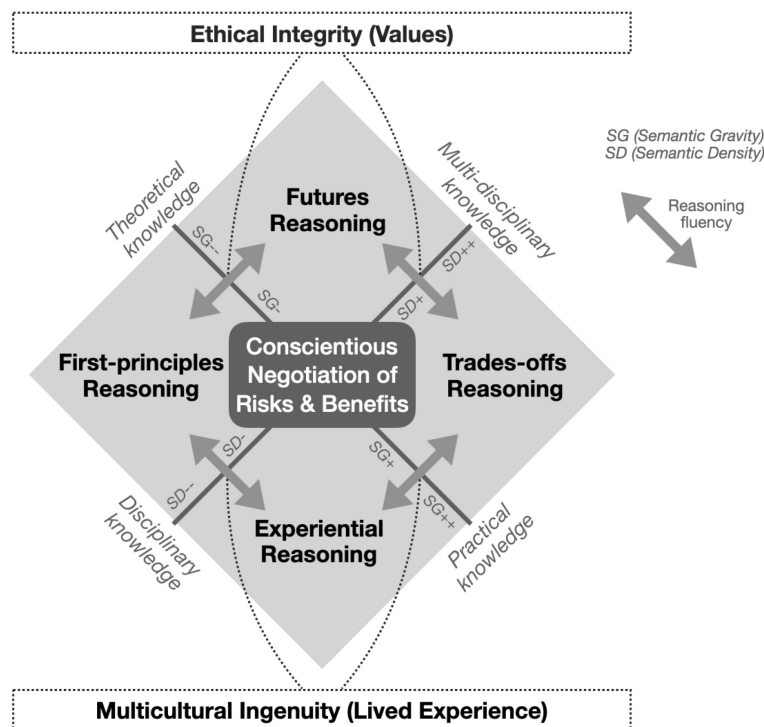


Fig. 1. The Conscientious Design Framework.

quadrants [24], indicated by the solid arrows in Fig. 1. This movement is what we call reasoning fluency. Such fluency is necessary for the designer to make explicit the conscientious negotiation of risks and benefits of design decisions. One of the ways that designers make reasoning fluency explicit is through discourse that can be written, visual, or oral. Furthermore, it is important that designers inform their designs using their multicultural ingenuity and ethical integrity and articulate these aspects as justification for their design decisions. Using multicultural ingenuity and ethical integrity can promote reasoning fluency and lead to transformative agency.

Multicultural ingenuity is a catalyst for reasoning fluencies across experiential, first-principles, and trade-offs reasonings (See the two dotted lines towards the bottom of Fig. 1). Multicultural ingenuity creates space for designers to bring in their transformative agency through leveraging their experiential and cultural knowledge throughout the design process. When emphasizing reasoning fluency as a form of transformative agency, a designer should be encouraged to enact their individual background and experiences inclusive of their cultural understandings to inform how they understand and reason through design requirements and disciplinary ideas.

While multicultural ingenuity focuses on previous experiences, ethical integrity looks at the possible futures of the design. Ethical integrity is situated as the catalyst for reasoning fluencies across futures, first-principles, and trade-offs reasoning (See the two dotted lines towards the top of Fig. 1). A designer enacts their ethical integrity through careful examination of the benefits and burdens of the design with their knowledge of multiple disciplines and design requirements. Through this careful examination, designers develop a morally committed practice of the design process that focuses on using their agency and values to help identify and address the intentional or unintentional transformative impacts of their design.

We view conscientious design as a novel approach that grounds design in the individualized cultures and values of the designer. Sanders [27] maps previous design approaches such as human-centered design, user-centered design, empathetic design, participatory design, and critical design across two spectrums. The first spectrum explains what is guiding the design process, the design requirements and iterations or applied research from multiple disciplines. The second one situates how users are positioned as subjects or partners. This second spectrum demonstrates how previous approaches to design focus design decisions

through the end user [3, 27]. Historically, human-centered design and user-centered design, two of the most well-known design approaches, challenged technology-centered design where designers impose decisions on intended users [28] to shift the focus towards designing for the end user [3]. The conscientious design framework represents a new shift away from over-relying on designing for the end user [6] towards focusing on design reasoning through the negotiation of risks and benefits which include the impacts on the end user. By describing how design reasoning is shaped by culture and values, the framework supports an understanding of design that is both personally grounded and socially transformative, an aspect often underrepresented in earlier design approaches.

4. Methods

4.1 Data Collection and Course Context

Our study uses 79 publicly available posters that students created individually as a final deliverable for their civil and electrical engineering courses at a college in Hawai'i. Students submitted these posters to their college's undergraduate research conference. Students developed these posters to present the project they developed in the course on designing a carbon-neutral or carbon-negative energy buildings through simulating solar energy projects and integrating heating and cooling mechanisms that could help Hawai'i reach its goal of carbon neutrality by 2045. Students used Aladdin, an AI-enabled CAD software, to model the building of their choice, design a solar project for the building, and generate multiple analyses that use generative AI tools to determine optimal specifications [29]. We tracked each poster using the identifier Aladdin assigns and named each poster in this publication after the first couple of words in their title to anonymize the students as much as possible.

Earlier deliverables for the course include posting scaffolded steps of their design project, including their modeled building, energy usage graph for that building, and their solar design iterations with energy capacity, visibility, and heating or cooling analyses. Along with these earlier deliverables related to the design process, students also submitted cultural elements related to the location of their building and ChatGPT prompts for their Introductions and Conclusions. In Fig. 2, we include the example of reiterated prompts provided to the students for their Introduction sections and the broader instructions for their use of ChatGPT in the Conclusion sections.

Students could choose how much and what to include from these deliverables in their poster to tell

Prompt:

Write the introduction section for a poster presentation about solar panel design.

Write a **brief** introduction section for a poster presentation about **effective** solar panels designed **for a high school campus**.

Write a brief introduction section for a poster presentation about effective solar panels designed for a high school campus **to offset the cost of electricity significantly, that also incorporates content from a college course on circuit analysis**.

Write a brief introduction section for a poster presentation about effective solar panels designed for a high school campus **in Honolulu** to offset the cost of electricity significantly, that also incorporates **the Thevenin equivalent circuits and solar panels in parallel and series** from a college course on circuit analysis.

Write a brief introduction section for a poster presentation **in three paragraphs** about effective solar panels designed for a high school campus in Honolulu to offset the cost of electricity significantly, that also incorporates the Thevenin equivalent circuits and solar panels in parallel and series from a college course on circuit analysis. ----->

Prompt:

Use ChatGPT to generate your conclusion section. Keep the length to either one brief paragraph, or two very brief paragraphs. This may take a few iterations. Post your ChatGPT prompt to the Padlet, and add the conclusion to your Google Slide poster.

Fig. 2. Example prompts provided by the students for the Introduction (Top). Assignment prompt provided to the students for the Conclusion (Bottom).

their design story following the template in Fig. 3 for a broad audience at the research conference. A picture of the poster template given to the students is shown in Fig. 3.

Through the conscientious design framework, we understand that students can enact their transformative agency when given authentic design projects that integrate purposeful design decisions [25]. In the case of this solar project, authenticity is met by students simulating solar design projects with multiple mechanisms and trade-offs. The purpose is met through the need to create a carbon-negative or carbon-neutral building to help Hawai'i reach its goal of carbon neutrality that provides opportunities for students to negotiate the criteria important to them.

Because the project is based on helping Hawai'i reach its goal of carbon neutrality, the design of the study also promotes ethical integrity through the

need to consider the social and environmental aspects of the design to reach this energy goal. Ethical integrity, along with multicultural ingenuity, are catalysts of reasoning fluency that promote students to enact their transformative agency. While the broader goal of carbon neutrality promotes ethical integrity, the student makeup of the college leads to more opportunities for multicultural integrity. About 88% of the students at the college are Hawai'i residents [30], so the students in these courses would likely have a personal and cultural connection to the locations they selected. One of the students sums up these connections to the place, saying in their poster that "[w]hen deciding what community center to choose as a model. I found that I wanted to choose one that is close to where I lived...so that it could feel more personal." With these relationships to place, we will illustrate in our findings how some students used their

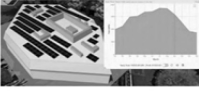
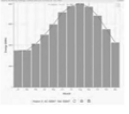
Introduction Explain the engineering problem you're trying to solve. Describe the design parameters. Try not to use too much jargon. It's okay to use pictures or graphics if it will help to clarify the purpose of your work. Why is this work important? Don't use any kind of fancy picture background. Just a plain white background is less distracting. Use a plain, non-serif font like Arial or Helvetica, so that the poster is easy to read. Be sure to mention the school campus you're trying to improve, and which building on the campus you focused on. Remember to share this Google Slide with me (hanaia@hawaii.edu) with editing access, so that I can help out with formatting and corrections.  Fig. 1 All figures should have descriptive captions, should be numbered in order, and each should be referenced in your narrative.	Design Describe your design for a solution to the problem you described in the introduction, and what you built or created as a prototype. Discuss the process you used to make your design decisions. If you already went through multiple design iterations, then you can describe all of them. Show pictures of your prototype, and use graphs or charts if it will help to clarify things. Rearrange your poster content into whichever columns fit best, so that it looks nice.  Fig. 2 Place as many/few figures as you want, in whichever locations on the poster you want. Testing Describe how you tested your prototype, and what you measured to determine the success of your design.  Fig. 3 Descriptive caption	Conclusion and Future Work Describe your next steps. Based on the test results of your prototype, describe the changes to your existing design that would improve the next iteration of your design. Emphasize why your work is interesting and significant. Try to tie it with other research in the field.  Fig. 4 Descriptive caption References Follow the format required by the conference, symposium, or event. If in doubt, just use APA formatting. You can reduce the font size for this section if you are running out of room. Acknowledgments Acknowledge the people who helped you with your work, and any entity that provided funding (like NSF or NASA) in one or two sentences at most. You can also reduce the font size for this section if you're running out of room.
--	--	--

Fig. 3. Poster template for final deliverable with prompts and requirements for each section.

cultural knowledge of these locations to guide their design decisions. Reasoning fluency is called forward through the final deliverable of the poster. The prompt of the poster asks students to discuss their design processes when making their design decisions and the discussion should articulate the negotiations they considered during their decision-making. These alignments with both transformative agency and the conscientious design framework illustrate why we chose to analyze this course, specifically its final deliverable of the poster.

4.2 Data Analysis

Prior studies of designers have effectively used discourse such as conversations, sketches, and writing to make sense of designers' thinking processes [31–33]. The nature of discourse we examined in this study is written discourse, retrieved from student design posters. To analyze the posters, we used a hermeneutic inquiry combining qualitative content analysis and thematic analysis [34]. We recognize that the posters are a succinct form of discourse that will not encapsulate all the design decisions that occurred throughout the course. Although concise, using a hermeneutic inquiry based on qualitative content analysis [35] allows us to interpret the students' chosen written texts as what the students believed were the most important aspects and decisions of their design processes.

Through this qualitative hermeneutic inquiry, we followed two cycles of coding where both cycles focused on being both descriptive and interpretive [34, 35]. The first three authors conducted an initial

exploratory coding [36] process and had discussions that led to the understanding that the students who often moved through the reasoning quadrants, outlined in the conscientious design framework [24], seemed to bring in their cultural knowledge located in the context of Hawai'i and discussed the social or environmental impacts of the design related to the goal of carbon neutrality, even though the assignment prompt did not require these aspects.

The first two authors used a pattern coding process [36] in the second cycle of coding to further interpret how these manifestations of the conscientious design framework appear or are lacking in the posters through the three aspects of transformative agency. As we noticed the reasoning quadrants in the first cycle, we coded portions of the poster that elicited the specific reasoning quadrants with short descriptions of what we interpreted as the students' design decisions. We analyzed these quotations with descriptions to identify patterns and later themes of how reasoning fluency may or may not have manifested as content analysis focuses on both manifested and latent content [37]. We also used the identified quotes to see how students used their cultural knowledge and the social or environmental impacts of their designs to influence their decisions acting as proxies for the catalysts of multicultural ingenuity and ethical integrity, respectively. These quotes related to multicultural ingenuity and ethical integrity helped to identify outliers that illustrate more fluent manifestations of conscientious design reasoning in students' written discourse.

To ensure rigor in our analytical process, we

conducted a validity check with these outlier posters because of their reasoning fluency. These posters move through multiple reasonings through enacting different reasoning fluencies that guided our discussions so that we would have a shared understanding of the coding process based on the conscientious design framework. This validity check ensured the integrity of the qualitative coding process as a form of ethical validation and brought about fruitful discussions to negotiate patterns as a form of process reliability [38]. While this first validity check focused on reasoning fluency, we conducted a second validity check with the same goals of improving integrity and bringing about fruitful discussions of patterns using two-dimensional data displays [36] that organized the cultural knowledge, as well as social and environmental impacts, alongside the sections of the poster. For the cultural knowledge data display, our Native Hawaiian author from Hawai'i completed that data display on their own as we decided that he would have a better perspective to identify cultural knowledge related to Hawai'i while the first two authors completed the social and environmental impacts data display together.

5. Results

Our analysis revealed five hierarchical ways conscientious design manifested in the context of a sustainable design project in Hawaii. Each level represents increased levels of the conscientious negotiation of risks and benefits that is brought out in students' design posters. We labeled these levels as following:

- Level 1: Technological Determinism.
- Level 2: Two Quadrants Reasoning.
- Level 3: Reasoning Quadrants without Fluency.
- Level 4: Conscientious Negotiation.
- Level 5: Transformative Agency.

At each level, we include examples from student posters to present our analysis of patterns that impacted reasoning fluency and to provide interpretations of aspects that may be inhibiting or promoting reasoning fluency. These results also address how conscientious design manifests in student work.

5.1 Level 1: Technological Determinism

The first level represents aspects within the posters where reasoning was not apparent or where we could not distinguish students' reasonings. In this level and the next, we also focus on ways students negotiate (or not) the outputs generated by AI tools that they use. The assignment prompt calls for an explanation of the engineering problem and a

discussion on design parameters which would have set up opportunities for design reasoning. Students used ChatGPT to help facilitate writing in the form of a research poster genre, with the expectation to see students edit these outputs in alignment with the assignment expectations. However, the Introduction sections of many posters exhibited a strong case of technological determinism. Technological determinism represents a larger pattern connected to the foundations of Western engineering and engineering education that relies on treating technical tools as neutral and depoliticizing design aspects [18–21].

We observe the use of ChatGPT in the Introduction and Conclusion sections of the poster to represent how students positioned this AI tool as technologically deterministic. Although this use of AI is not related to designing solar energy projects, the conscientious design framework recognizes the articulation of reasoning as central to the design process. Despite the instructor warning the students of the biases and misinformation of ChatGPT in their assignment prompt, there are instances where students appear to not realize they are using ChatGPT in a technologically deterministic manner. Below, we cite the entire Introduction of the “Shining Light” poster as an example. The metaphor-filled Introduction suggests heavy reliance on ChatGPT.

Aloha! Embark on a sun-soaked journey through the Pacific breeze as we explore the harmonious blend of solar panel farms and circuit analysis, with a special gaze upon Thevenin equivalent circuits. In the limited canvas of Hawaii's vibrant landscape, where space is a treasure, our poster presentation unveils the creative magic weaving through compact solar arrays. Discover how Thevenin's wizardry transforms the challenge of limited space into an opportunity for ingenious design, capturing the essence of Hawai'i's boundless sunshine. Join us for this tropical odyssey where solar panels dance to Thevenin's rhythm, promising a sustainable, space conscious aloha to a brighter future. This project was conducted in [school name] right off the [location].

Introductions like these reinforce technological determinism through perpetuating colonial understandings embedded in metaphors. The first colonial understanding is the celebration of tourism with the phrases “sun-soaked journey through the Pacific” and “tropical odyssey.” These phrases reinforce a commodified understanding of Hawai'i as a tropical paradise for colonial possession through the industry of tourism [39], one of the two largest industries in Hawai'i that erase Native Hawaiian connections to and conceptions of the

natural world [40]. The second colonial understanding embedded in multiple posters is Hawai'i being described as isolated with limited space. This poster exemplifies this understanding through the phrases *"In the limited canvas of Hawai'i's vibrant landscape, space is a treasure"* and *"space conscious aloha to a brighter future."* Treating Hawai'i as isolated islands without enough space casts the illusion that Hawai'i needs to depend on the United States (US). A lot of posters mentioned how Hawai'i imports most of its food and energy [41] maintaining this concept of dependency. However, US colonialism in Hawai'i actively imposes isolation as a tool to maintain economic and political dependency so that the US can continue to profit off Hawaiian land, people, and resources [42, 43].

We do not know exactly how much the student directly copied or revised the outputs of ChatGPT because these colonial understandings are also socialized in Hawai'i. However, the fact that ChatGPT with inherent colonial underpinnings [44] helped the students develop their Introduction and Conclusions represents possible locations where students reasoning is muddled or erased and where students are seemingly not questioning the tool. Through this lack of questioning, students are intentionally or unintentionally taking an objective stance through a technological deterministic perspective where the technology, in this case ChatGPT, drives social change of maintaining the power dynamics held within colonial ideologies of Hawai'i. This objective stance also conceals design reasoning, illustrating a Level 1 use of conscientious design where the student is overlooking the political, cultural, and economic impacts of their words.

5.2 Level 2: Two Quadrants Reasoning

The second level represents the posters that provided evidence of reasoning in two quadrants that are positioned opposite to each other, most commonly the experiential reasoning and futures reasoning quadrants. However, the posters did not exhibit reasoning fluency lacking connections with the other reasoning quadrants. As we explained in the framework, experiential reasoning comes from experiments (in this case conducted in Aladdin) as well as from prior knowledge and experiences while futures reasoning is thinking through the different possible futures and consequences of the design options. Aladdin's generative AI capabilities create analyses that would fall under experiential reasoning. While we do view the generative AI capabilities of Aladdin as a useful tool for these solar design projects, this second level pattern represents how heavy reliance on the output of these capabilities can be a barrier to reasoning fluency.

Specifically, these posters manifested limited experiential learning and reasoning with respect to the outputs of Aladdin's analyses and limited futures reasoning to the broad impact of the design on Hawai'i's energy landscape. Students can flow between these reasonings through first-principles reasoning when they make generalizations from their experiments or through trade-offs reasoning when they make a decision based on competing requirements. However, at this second level, the posters lacked this flow evident in the "Sustainable Schools" poster where the goal of the student's design project is to maximize energy production for a public school building in Hawai'i. The student decided to add solar panels to the roof of their building *"until the roof was completely covered to allow for maximum energy production"* while also implementing a solar canopy in the parking lot and a solar farm behind the building. The poster explicitly states in the Testing section that *"the goal of each installation was to produce as much energy as possible,"* leading to a design that produced about 850,000 kWh annually while the building only needed 190,000 kWh based on Aladdin's analysis. There was evidence of futures reasoning in the statement that *"there would be a surplus of about 800,000 kWh that could be utilized elsewhere throughout the school."* We interpret this maximizing of energy yield as the student doing everything in their power to output the highest energy capacity situating their reasoning in the experiential reasoning quadrant with the goal of providing energy to the entire school as a form of futures reasoning. However, not considering any other risks and benefits for their design illustrates a technologically deterministic view of valuing a technical output.

While the "Sustainable Schools" poster illustrates how some students ignored the connection between reasoning quadrants leading to a lack of reasoning flow, there are also examples where students tried to negotiate reasonings through these intermediary quadrants. However, these negotiations missed the mark and also lacked reasoning fluency. A common example of a misaligned negotiation is through the posters where students wanted their solar designs to be an educational tool to further the social impact of their design. Most of these posters that mentioned the solar design being an educational tool also explicitly or implicitly discussed or depicted their visibility analyses as a tradeoff. The visibility analysis is one of the generative AI analysis tools in Aladdin that measures how well the solar project is out of human sight to maintain the aesthetic of Hawai'i, an important tradeoff for solar panel implementations usually.

In these examples, we notice evidence of students moving from experiential reasoning to trade-offs reasoning in the way they utilized Alladin's visibility analysis feature. The posters reflect considerations of futures reasoning through the articulation of the added educational value of a solarized school building. However, an important consideration and trade-offs reasoning was missing. If the solarized school building had an educational value, visibility would need to be increased, perhaps maximized, so students at this school could see and interact with the solar project. Because these students continued to incorporate the visibility analysis that hides their solar panel project, we interpret this as another way that students positioned these technical outputs of the Aladdin software as objective and missed the opportunity to move through trade-offs reasoning towards futures reasoning through not negotiating the purpose of the visibility analysis with their goals. From this interpretation, students are using Aladdin's analyses as an objective tool that does not require any type of assessment or reasoning from them. Promoting a more conscientious negotiation could have helped the student find a different solution to the tradeoff of aesthetics, such as blending in the visual design of their solar panel project with the aesthetic of the school. We will come back to this example in a later section.

5.3 Level 3: Reasoning Quadrants without Fluency

Like the first two levels, the third level demonstrates how positioning technical aspects as objective design outputs discourages reasoning fluency. However, the third level signifies how posters could occupy connected reasoning quadrants but

without fluency across the reasoning quadrants. As a reminder, the poster template calls for students to "Discuss the process you used to make design decisions" in the Design section, so we expected evidence of reasoning fluency. However, posters that exhibited this third pattern generally listed discrete factors that students considered without reasoning fluency. The "Solar Panel Design" poster stated:

The design process was centered around several factors: capacity (energy required vs. space), weather patterns (can we obtain enough energy year-round), and visibility (how the panels looked and where they were). Thus, the panels were strategically designed, staged and analyzed in the area of the [school name] campus.

Energy capacity, weather patterns, and visibility are all analyses done by the Aladdin software. The student describes that they took the results of these analyses to make their decisions but not what decisions they made, which situates the student within both the experiential reasoning quadrant from the output of the analyses and the trade-offs reasoning quadrant from the consideration of the multiple analyses. The "Solar Panel Design" poster illustrates the first-principles reasoning implicitly with the addition of Fig. 4, a depiction of the analyses.

Fig. 4 includes the energy capacity analysis with the graph on the top right that shows whether the student met the design criteria of designing a carbon-negative building, as the lighter lower bars produce more energy than the darker upper bars. The student also includes a heliodon (the circle

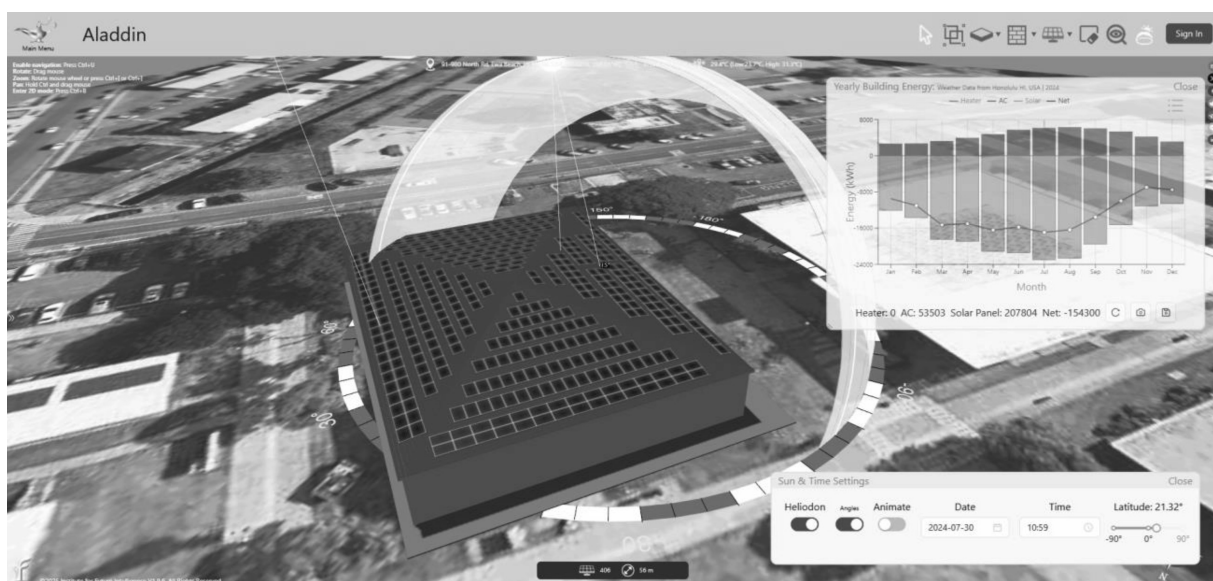


Fig. 4. Design for "Solar Panel Design" Poster that includes an energy output graph and heliodon that helps decide the ideal tilt for the solar panels.

around the building) which tracks the movement of the sun that would help the student determine an optimal solar panel position. The inclusion of this heliodon represents first-principles reasoning because we can infer that the student used the heliodon to change panel angles to decide on an energy capacity level that they wanted.

Despite occupying three connected reasoning quadrants, “Solar Panel Design” does not explicitly describe how they moved between these quadrants because the student lists considerations or depicts analyses that are both connected to analytical outputs. We interpret this lack of movement between quadrants or lack of reasoning fluency as students valuing final design outputs and products and not the process of negotiation that informs design decisions.

5.4 Level 4: Conscientious Negotiation

In the previous themes, we discussed how relying on technical aspects hides reasoning fluency and how objectivity through technological determinism is a possible mechanism that blurs and misaligns reasoning. In this theme, we explain how using multicultural ingenuity and/or ethical integrity can promote reasoning fluency representing higher levels of conscientious negotiation.

Many of the posters mentioned a cultural or social understanding of the place, land division, or island in Hawai‘i where the site is situated using specific Native Hawaiian cultural elements. Finding these cultural elements was one of the earlier deliverables; however, students did not have to incorporate these cultural elements into their posters. As a reminder, we see the inclusion of cultural knowledge in posters as a proxy for students enacting their multicultural ingenuity.

Some students described historical significance of places, specific cultural features like loko i‘a or fishponds in that place and Native Hawaiian mo‘o-lolo or stories that are rooted in place [45]. The most common use of cultural knowledge was introducing the reader to the ahupua‘a or pie-shaped land division in which their building is situated. For context, the ahupua‘a system divided land in terms of freshwater resources to develop relationships between upland and downland people, and more importantly, with the natural world to ensure the abundance and health for all through an economy based in regenerative resources and relationships [46]. Through situating their buildings into the ahupua‘a system, students are actively demonstrating their transformative agency by drawing on their cultural knowledge. Similarly, students are also demonstrating pluralism through their use of ahupua‘a, bringing their individualized cultural and geographical understandings towards a collective

renewable energy future [14] throughout Hawai‘i. “Optimizing Solar” makes this connection in the following sentences:

This design draws inspiration from my local ahupua‘a of Waiakea-Uka in Hilo. The region, known for its fertile soil, fresh water, and agricultural heritage, embodies a balance with nature that this project aims to replicate in modern building practices. By using resources thoughtfully and reducing environmental impact, this design aligns with sustainable principles rooted in Hawai‘i’s cultural and natural landscapes.

This statement illustrates the student explicitly connecting the values of their ahupua‘a and the ahupua‘a system at-large to their solar energy project focused on regenerative resource management in the current energy landscape, representing a movement from their experiential reasoning based in their cultural knowledge of place to their first-principles reasoning with the specific disciplinary knowledge of “modern building practices” learned in the course as well as to trade-offs reasoning by negotiating “using resources thoughtfully and reducing environmental impact.” Although this example demonstrates reasoning fluency through multicultural ingenuity, we recognize that this reasoning represents broader understandings of the design rather than informing specific design decisions which is representative of what we classify as a Level 4.

The forms of reasoning fluency through multicultural ingenuity were most frequently in the Introduction section of the posters. This makes sense as the Introduction section sets up the location of the building and utilizes ChatGPT. We found a similar pattern with the discussions of societal and environmental impacts, or proxies of ethical integrity, most frequently being in the Introduction and Conclusion sections, the two sections that focus on broader impacts of the design.

These discussions surrounding ethical integrity explained how the designs addressed the future impacts through trade-offs reasoning or broad disciplinary knowledge (i.e., first-principles reasoning). Examples of these impacts include: (1) decreasing the over-reliance on imported fossil fuels that make up around 80% of Hawai‘i’s energy grid [41]; (2) reducing energy costs for residents as the need for cooling increases with increasing tropical temperatures; and (3) protecting the natural and picturesque environment in Hawai‘i. In these examples, ethical integrity appears to catalyze fluency through trade-offs and first-principles reasonings towards futures reasoning.

While reasoning fluency through multicultural ingenuity and ethical integrity are evident throughout these examples, these aspects of transformative

agency are disproportionately represented in the Introduction and Conclusion sections. In the Design and Testing sections, where specific design decisions should be discussed, the conversations were prominent around the measurable, technical aspects of the design. We interpret these patterns as students missing opportunities for reasoning fluency using multicultural ingenuity and ethical integrity in support of the broader impacts of their design by relying solely on the technical aspects. We recognize that these usage patterns are likely influenced by the set-up of the final deliverable; however, a discussion of the design process is stated in the prompt of the Design section. Thus, we expected more examples of ethical integrity and multicultural ingenuity in the Design section of the posters and maintain our interpretation of students prioritizing the technical over other aspects that may be hindering their reasoning fluency in the Design and Testing sections.

5.5 Level 5: Transformative Agency

At this final level, we offer two outliers, one that exemplifies a specific use of multicultural ingenuity on design decisions and another that exemplifies a specific use of ethical integrity on design decisions. These examples demonstrate how using multicultural ingenuity and ethical integrity to make specific design decisions promotes higher levels of reasoning fluency and conscientious negotiation to move towards transformative agency in design.

We observed the richest representation of cultural knowledge in the “Designing Energy” poster

where the student used their knowledge of place in the Introduction to guide their design rather than a broad generalization. In the Introduction, the student explains how the name of the ahupua‘a where they are from influenced their design:

Niumalu translates to ‘Shaded Coconut Trees’ as a prevalent (though not as much in current time) amount of coconut trees dot my homeland, providing shade from the harsh Hawaiian sun . . . From this name, a strategy can be devised towards energy efficiency.

In the Design section, the student ensures that their design involves the planting of Native trees, specifically “*canopy micro trees and palms*” with the latter representing coconut trees, alongside installing a solar panel for the building in their ahupua‘a of Niumalu as shown in Fig. 5.

“Designing Energy” is an example where centering multicultural ingenuity situates the design in the experiential reasoning quadrant. The student’s knowledges of place and Native trees allows them to articulate their rationale to integrate coconut trees into their design for shade, demonstrating first-principles reasoning of heating and cooling mechanisms built into Aladdin, as well as trade-offs reasoning between energy efficiency and environmental/cultural revitalization that are often socially constructed as at odds to each other.

The ethical integrity outlier goes back to designing a solar project that is also an educational tool to illustrate how a more aligned and conscientious negotiation of trade-offs is elicited through ethical



Fig. 5. Design for “Designing Energy” that uses the default trees in Aladdin to represent coconut trees and its relationship to the ahupua‘a of Niumalu. It should be noted that Aladdin only implements trees common in Boston and California, so the student denoted that the trees in the figure are stand-ins for coconut trees.

integrity. The “Integrating Solar” poster demonstrates a more aligned approach in the Design Section:

Both rooftop solar and solar farms were modeled in Aladdin, however only one design satisfies the demand for sustainability minded STEM education. By using the solar farm, students can be allowed hands on access to the solar panels. Classes can be designed around this interface teaching material related to circuits and circuit analysis, maintenance, and sustainability.

In this example, the student chose a solar farm which is the only type of solar project that is located on the ground. “Integrating Solar” exhibits ethical integrity through the reasoning fluency from first principles to futures reasoning with the disciplinary knowledge to identify possible curricular units with a solar farm as an educational tool. They also move from trade-offs reasonings to futures reasonings by ignoring the previously discussed visibility analysis that is one of the intermediate deliverables to better align with their value of education and challenge the notion of the visibility analysis as an objective tool.

Both outliers demonstrate how these students moved beyond the requirements of the poster to articulate how their multicultural ingenuity and ethical integrity played an integral role in their design decisions exemplifying transformative agency.

6. Discussion – Moving towards Transformative Agency through Conscientious Design

The first goal of our study is to introduce the conscientious design framework that we spent the majority of the time doing in Section 3. We further developed the different aspects of the framework related to transformative agency when discussing reasoning fluency, especially with respect to the catalysts of multicultural ingenuity and ethical ingenuity. Guided by this framework, we were able to identify the manifestations of conscientious design through introducing and exemplifying the different patterns of reasoning fluency in the Results Section. Informed by these results, we provide recommendations to promote transformative agency through conscientious design. Our first recommendation is to help designers understand that the technical and technological aspects of design, such as analytical outputs and AI tools, are design considerations that should only be included when promoting reasoning fluency.

The first four levels in the results that we framed as the different levels of conscientious negotiation showed how relying on and not questioning the

technical aspects of design prevented reasoning fluency. The first level illustrates how taking a purely objective stance in the use of ChatGPT resulted in neglecting the social, political, and environmental impacts of their design decisions, leading to no indication of reasoning. Riley [21] describes this objective stance as built into the foundation of engineering and engineering education as a mindset that works to maintain designs as neutral and apolitical [20]. The second and third levels demonstrate that using multiple reasonings does not necessarily translate to reasoning fluency as the examples showed that many of the students used their analytical outputs as the only justification for their design decisions. We connect this reliance on analytical outputs as evidence of how Western engineering and engineering education value industrialized concepts like efficiency and optimization [19] which represent Aladdin’s analytical outputs. Gelles and colleagues [18] reported that the overvaluing of industrialized concepts among engineering students can lead them to overlook non-technical aspects that align with the evidence that the students provided in levels 2 and 3. The habit of overlooking non-technical aspects through prioritizing the technical aspects of design is also reinforced in level 4, where the students limited their uses of multicultural ingenuity and ethical integrity to connect the broader influences and impacts of their designs rather than using their multicultural ingenuity and ethical integrity to make specific design decisions.

Our second recommendation stems from these limited uses in level 4, to encourage designers to integrate their multicultural ingenuity and ethical integrity throughout all aspects of the design process to promote reasoning fluency. More specifically, student designers should be given opportunities to articulate the ways that their multicultural ingenuity and ethical integrity influence their design decisions. The students who demonstrated conscientious design at level 5 were the outliers who articulated how their multicultural ingenuity and ethical integrity impacted their design decisions. Our analysis of these cases demonstrated how the interaction between reasoning fluency, multicultural ingenuity, and ethical integrity emphasizes pluralism [3, 15] so that individual designers can use their own perspectives and actions to move towards a collective change [12, 14, 15] around the shared goal of carbon neutrality in Hawai’i. This interaction cultivates transformative agency, manifested in conscientious design, to move beyond the technical to thoroughly consider all aspects of a design from individualized backgrounds, experiences, and values towards social transformation [10].

Based on these two recommendations, it is obvious that our overarching recommendation is to find ways for designers to promote and articulate reasoning fluency. Instructors of design should produce pedagogical tools and approaches that promote students to articulate their reasoning fluency to justify their decisions as a form of conscientious negotiation. One such tool from our previous work is the engineering design coaching tool [47] that provides questions instructors should ask to provoke reasoning within each quadrant and reasoning fluency between quadrants. Also, the design of deliverables can play a huge role as exemplified by the outlier students who moved beyond the requirements to enact their transformative agency aligning with previous work in maker-spaces [17].

We argue that conscientious design is an approach that challenges the objectivity built into the historical and cultural foundation of our field, including design [21]. A conscientious design approach accomplishes this challenge through centering transformative agency by explicitly articulating reasoning fluencies to move beyond the technical aspects of design catalyzed through multicultural ingenuity and ethical integrity. Through this focus on transformative agency in design, a conscientious design approach grounds reasoning in the knowledges of the designer, positioning this approach in friendly contrast to other design approaches that places the emphasis only on users [3, 6, 27].

7. Conclusion

Through a hermeneutic inquiry of design posters of an AI-enabled solar project in Hawai'i, we illustrated how conscientious design manifests in student work. Our analysis revealed five increasingly conscientious levels of design reasoning, ranging from technological determinism as an inhibitor to reasoning fluency to conscientious negotiation with the highest-level of negotiation being transformative agency. These findings demonstrate how design

is a reciprocal relationship between the individual and society where each shape and transform one another. The conscientious design framework makes this relationship transparent through promoting reasoning fluency that centers the negotiation and rationale behind design decisions. The framework situates both human ingenuity, which is inherently multicultural, and ethical integrity as equally important as technical aspects in decision-making.

A contribution of our study is the methodological approach of analyzing posters through a hermeneutic inquiry. These posters are concise versions of student's design process that uncover the manifest and latent aspects of design that students prioritized; however, the posters are limited in depth. Future work should also conduct interviews, or reflection prompts with students to gain deeper insights into the design aspects they prioritize. In addition, a quantitative content analysis approach would encompass generalizable insights related to reasoning fluency.

In support of engineering design education, the conscientious design framework can guide design reviews. These reviews emphasize reasoning fluency as evidence that students can negotiate diverse aspects of design and related risks and benefits, including negotiating their agency with respect to AI. Promoting reasoning fluency and creating space for transformative agency are integral to moving towards a well-grounded and socially transformative designed world. Eliciting active and conscientious negotiation is especially important in the age of artificial intelligence (AI), so we can most effectively determine the risk and benefits of AI as a design tool and build competencies for a healthy human-machine co-agency.

Acknowledgments – This work was partially funded by NSF Grant #2405431 and partially by Purdue University's Bridge Funding Program. We would like to acknowledge both funding sources that made this work possible. We also want to thank the students in these courses for finding ways to represent who they are through their designs. There was so much to glean from their transformative work, and we could feel their commitment to design for the well-being of Hawai'i.

References

1. C. L. Dym, Engineering design: So much to learn, *International Journal of Engineering Education*, **22**(4), p. 422, 2007.
2. J. Morley, L. Floridi, L. Kinsey and A. Elhalal, From what to how: an initial review of publicly available AI ethics tools, methods and research to translate principles into practices, *Science and Engineering Ethics*, **26**(4), pp. 2141–2168, 2020.
3. C. B. Zoltowski, W. C. Oakes and M. E. Cardella, Students' ways of experiencing human-centered design, *Journal of Engineering Education*, **101**(1), pp. 28–59, 2012.
4. P. Wright and J. McCarthy, Empathy and experience in HCI, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Florence, Italy, April 5, pp. 637–646, 2008.
5. R. Benjamin, *Race After Technology: Abolitionist Tools for the New Jim Code*, Polity, Medford, MA, 2019.
6. L. Van Velsen, G. Ludden and C. Grünloh, The limitations of user-and human-centered design in an eHealth context and how to move beyond them, *Journal of Medical Internet Research*, **24**(10), p. e37341, 2022.
7. M. Hamington, Integrating care ethics and design thinking, *Journal of Business Ethics*, **155**(1), pp. 91–103, 2019.

8. M. W. Tracey and A. Hutchinson, Uncertainty, agency and motivation in graduate design students, *Thinking Skills and Creativity*, **29**, pp. 196–202, 2018.
9. J. Tholander, M. Normark and C. Rossitto, Understanding agency in interaction design materials, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Austin, Texas, USA, May 5, pp. 2499–2508, 2012.
10. J. W. Mutegi, The inadequacies of “Science for All” and the necessity and nature of a socially transformative curriculum approach for African American science education, *Journal of Research in Science Teaching*, **48**(3), pp. 301–316, 2011.
11. S. R. Daly, R. S. Adams and G. M. Bodner, What does it mean to design? A qualitative investigation of design professionals’ experiences, *Journal of Engineering Education*, **101**(2), pp. 187–219, 2012.
12. Ş. Purzer and T. Abane, Fundamental research: A framework for socially transformative engineering through conscientious design, *Proceedings of the 2024 ASEE Annual Conference*, Portland, Oregon, USA, June 23, 2024.
13. M. Emirbayer and A. Mische, What Is Agency?, *American Journal of Sociology*, **103**(4), pp. 962–1023, 1998.
14. A. Haapasaaari, Y. Engeström and H. Kerosuo, The emergence of learners’ transformative agency in a Change Laboratory intervention, *Journal of Education and Work*, **29**(2), pp. 232–262, 2016.
15. D. Paris and H. S. Alim, What are we seeking to sustain through culturally sustaining pedagogy? A loving critique forward, *Harvard Educational Review*, **84**(1), pp. 85–100, 2014.
16. H. Kerosuo, Transformative Agency and the Development of Knotworking in Building Design, in M. Geller and S. Paloniemi (eds.), *Agency at Work: An Agentic Perspective on Professional Learning and Development*, Springer, pp. 331–349, 2017.
17. A. Kajamaa and K. Kumpulainen, Agency in the Making: Analyzing Students’ Transformative Agency in a School-based Makerspace, *Mind, Culture, and Activity*, **26**(3), pp. 266–281, 2019.
18. L. A. Gelles, J. A. Mejia, S. M. Lord, G. D. Hoople, and D. A. Chen, Is it all about efficiency? Exploring students’ conceptualizations of sustainability in an introductory energy course, *Sustainability*, **13**(13), p. 7188, 2021.
19. L. Vanasupa, L. Schlemer, R. Burton, C. Brogno, G. Hendrix and N. MacDougall, Laying the Foundation for Transdisciplinary Faculty Collaborations: Actions for a Sustainable Future, *Sustainability*, **6**(5), pp. 2893–2928, 2014.
20. E. A. Cech, The (mis)framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers’ ability to think about social injustices, *Engineering Education for Social Justice: Critical Explorations and Opportunities*, pp. 67–84, 2013.
21. D. Riley, Mindsets in Engineering, in D. Riley (ed.), *Engineering and Social Justice*, Springer, pp. 33–45, 2008.
22. J. A. Leydens and J. C. Lucena, *Engineering justice: Transforming engineering education and practice*. Piscataway, New Jersey: Wiley-IEEE Press, 2017.
23. Criteria for Accrediting Engineering Programs, 2025–2026 | ABET, <https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/>, Accessed 23 October 2025.
24. J. Quintana-Cifuentes and S. Purzer, Semantic fluency in design reasoning, *International Journal of Engineering Education*, **38**(6), 2022.
25. C. Schimpf, Ş. Purzer, J. Quintana-Cifuentes, E. Sereviene and C. Xie, What does it mean to be authentic? *Design Thinking: Research, Innovation, and Implementation*, **3**, p. 87, 2022.
26. S. Purzer, Socially-transformative engineering pedagogy, *National Association for Research in Science Teaching (NARST) Annual Conference*, Denver, 2024.
27. L. Sanders, An Evolving Map of Design Practice and Design Research, *Interactions*, **15**(6), pp. 13–17, 2008.
28. K. Krippendorff, *The semantic turn: A new foundation for design*, Routledge, 2005.
29. C. Xie, X. Ding and R. Jiang, Using computer graphics to make science visible in engineering education, *IEEE Computer Graphics and Applications*, **43**(5), pp. 99–106, 2023.
30. University of Hawai‘i Institutional Research Office, <https://www.hawaii.edu/campuses/kapiolani/>, Accessed 28 July 2025
31. C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg and J. Saleem, Engineering design processes: A comparison of students and expert practitioners, *Journal of Engineering Education*, **96**(4), pp. 359–379, 2007.
32. R. S. Adams and J. A. Siddiqui, *Analyzing design review conversations*, Purdue University Press, 2016.
33. Ş. Purzer, The relationship between team discourse, self-efficacy, and individual achievement: A sequential mixed-methods study, *Journal of Engineering Education*, **100**(4), pp. 655–679, 2011.
34. G. A. Bowen, Document analysis as a qualitative research method, *Qualitative Research Journal*, **9**(2), pp. 27–40, 2009.
35. K. Krippendorff, *Content analysis: An introduction to its methodology*, Sage publications, 2018.
36. J. Saldaña, *The Coding Manual for Qualitative Researchers*, Sage Publications Ltd, Thousand Oaks, CA, 2009.
37. A. Kleinheksel, N. Rockich-Winston, H. Tawfik and T. R. Wyatt, Demystifying content analysis, *American Journal of Pharmaceutical Education*, **84**(1), pp. 127–137, 2020.
38. J. Walther, N. W. Sochacka, L. C. Benson, A. E. Bumbaco, N. Kellam, A. L. Pawley and C. M. L. Phillips, Qualitative research quality: A collaborative inquiry across multiple methodological perspectives, *Journal of Engineering Education*, **106**(3), pp. 398–430, 2017.
39. H.-K. Trask, Lovely hula lands: Corporate tourism and the prostitution of Hawaiian culture, *Border/Lines*, **23**, 1991.
40. E. K. Wright and B. J. N. Balutski, Ka‘Ikena a ka Hawai‘i: Toward a Kanaka ‘Ōiwi critical race theory, in K.-A. R. K. N. Oliveira and E. K. Wright (eds), *Kanaka ‘Ōiwi methodologies: Mo‘olelo and metaphor*, University of Hawai‘i Press, pp. 86–108, 2016.
41. G. Kent, Food Security in Hawai‘i, in J. Chirico and G. S. Farley (eds), *Thinking Like an Island: Navigating a Sustainable Future in Hawai‘i*, University of Hawai‘i Press, pp. 28–45, 2015.
42. M. Arvin, *Possessing Polynesians*, Duke University Press, 2019.
43. E. Hau‘Ofa, Our sea of islands, *The Contemporary Pacific*, **6**(1), pp. 429–442, 1994.
44. K. Rice, ChatGPT and World History Essays: An assignment and its insights into the coloniality of generative AI, *Teaching History: A Journal of Methods*, **49**(1), pp. 49–55, 2025.
45. J. H. Osorio, *Remembering Our Intimacies: Mo‘olelo, Aloha‘Āina, and Ea*, U of Minnesota Press, 2021.
46. K. Beamer, K. Elkington, P. Souza, A. Tuma, A. Thorenz, S. Köhler, K. Kukea-Shultz, K. Kotubetey and K. B. Winter, Island and indigenous systems of circularity: How Hawai‘i can inform the development of universal circular economy policy goals, *Ecology and Society*, **28**(1), 2023.
47. S. Purzer, C. Schimpf, J. Quintana-Cifuentes, E. Sereviene, I. Lingam and R. Jiang, Refine by Design: An engineering design coaching tool for supporting student reasoning, *Science Teacher*, **89**(1), pp. 35–39, 2022.

Austin Morgan Kainoa Peters is a PhD candidate in the School of Engineering Education at Purdue University. As a Native Hawaiian, his research focuses on resisting settler colonialism through Native ideologies to reconceptualize sustainability towards prioritizing a kinship with the natural world.

Jiwon Kim is a PhD student in the School of Engineering Education at Purdue University. She earned her BSc in Earth Science Education and MSc in Human-Computer Interaction, both at Seoul National University. Her research focuses on K-12 STEM education, curriculum development, quantum education, and learning technology for engineering education.

Şenay Purzer is a professor in the School of Engineering Education at Purdue University. Her expertise includes design reasoning fluency and the integration of engineering in pre-college education. She developed the conscientious design framework to promote engineering reasoning for sustainable, future-focused, and ethical design.

Aaron Hanai is an Associate Professor in Engineering and Physics at Kapi'olani Community College in the Math and Sciences Department.

Charles Xie is the Founder, President, and CEO of the Institute for Future Intelligence. He is a main developer of the Aladdin software used in this study.