

Engineering Design Learning through Community Centred Sustainability Innovations

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ABSTRACT

Engineers must be prepared to address societal challenges with both technical skills and contextual understanding, yet middle-year undergraduate curricula often lack hands-on design opportunities. This study described a second-year, United Nations Sustainable Development Goal (UN SDG)-aligned project-based learning (PjBL) experience in which 43 students worked in teams to design and prototype devices addressing local sustainability challenges in waste, water, and energy. Student learning and perceptions were evaluated through post-project written reflections, which were analyzed using an inductive thematic approach. Reflections indicated that students developed stronger connections to their communities and shifted from viewing sustainability as a distant problem ('they') to seeing it as a shared responsibility ('we'). These findings highlight how integrating UN SDG framing with hands-on design in middle-year courses can enhance learning and support engineering student development. The paper also discusses options for scaling and adapting the intervention across different courses and institutional contexts.

KEYWORDS

Engineering design,
Sustainability,
Hands-on, undergraduate,
Project-based learning

PUBLICATION

Submitted:
8th October 2025

Accepted after revision:
8th March 2026

Introduction

An engineering education should prepare students to address humanity's challenges with both technical and contextual capabilities. Numerous hands-on, sociotechnical (National Academy of Engineering (1991). Leydens, et. al. (2018), Ertas, A. (2018), Gelles & Lord (2021), Chen et. al. (2020), Przestrzelski, et. al. (2019), Reddy et. al. (2018)) engineering design and project-based learning (PjBL) experiences are critical elements in this preparedness (National Academy of Engineering (2004), (2005) & (2009)), as underscored by the prominence of engineering design throughout ABET

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undergraduate program accreditation requirements (the standard accreditation agency in the United States and used in 41 other countries) (ABET(2023)). The United Nations (UN) Sustainable Development Goals (SDG) provide a shared call-to-action for globally aware and responsible students, and therefore a roadmap for engineering educators in the creation of PjBL experiences that can help cultivate the needed preparedness and awareness in 21st century engineering practitioners (United Nations (2025)).

Hands-on engineering design has become standard in first-year (such as Dickrell & Virguez, (2019), Fentiman.,et. al. (2001), Lin et. al. (2017), Swenson et. al. (2014). Qi et. al. (2021), Knight et. al. (2003)) and senior-year (ABET (2023)) undergraduate engineering student experiences, but the second and third years are often devoted to foundational, technical coursework (such as statics, thermodynamics, and fluid mechanics) devoid of hands-on design experiences. Sometimes these courses do incorporate an open-ended design project, but the deliverable is often a theoretical solution or simulation, rather than requiring students to build and test their designs (and therefore confront their failures, which is a critical part of the iterative engineering design process (Henrikson et. al.(2021), Smith & Hendrikson (2016), Trueman(2014)). For students, this can be experienced as an ‘engineering bait-and-switch,’ which lures them into engineering through compelling, hands-on introductory courses before switching into fundamentals-first, theoretical approaches (Lachney & Nieuwsma,(2015)).

The subject of this paper is a hands-on, PjBL experience that was designed to mitigate this issue by implementing it into a required second-year engineering course. This sociotechnical and community-focused project was designed to cultivate humanity-centred approaches for designing a sustainable future by directly addressing four of the 17 UN SDG:

- Goal 6: Clean Water and Sanitation—Ensure availability and sustainable management of water and sanitation for all.
- Goal 7: Affordable and Clean Energy—Ensure access to affordable, reliable, sustainable and modern energy for all.
- Goal 11: Sustainable Cities and Communities—Make cities and human settlements inclusive, safe, resilient and sustainable.
- Goal 12: Responsible Consumption and Production—Ensure sustainable consumption and production patterns. (United Nations (2025))/

In PjBL course experiences prior to engaging in this project, the students were provided with problem statements and asked to generate designs based on established user needs. This approach is standard in many engineering education courses. In reality, the foundation of humanity-centred design is co-identifying and scoping a problem, then working to identify solutions that satisfy unmet user needs. In this project, the students were tasked with identifying (through research and interviews) an unmet community need related to the listed UN SDG, then designing, building, and testing prototypes to meet that need. Specifically, student teams were challenged to design a device and/or system to increase the university and local community’s sustainability and environmental resilience with respect to waste, water, and/or energy. The project was intentionally broad and open-ended, but structured with key deliverables along the way to keep the teams on track. This paper details the course and project design, as well as student and instructor reflections from the learning experience. Additionally, suggestions are made for how this project could be scaled and implemented in other educational settings to facilitate UN SDG learning experiences for engineering students.

Framework

This study is grounded in multiple complementary engineering education perspectives. Experiential learning theory (Kolb (1984)) emphasizes learning through cycles of concrete experience, reflection, conceptualization, and experimentation, providing a foundation for understanding how hands-on, design-build-test experiences support engineering skill development. Project-based learning (PjBL) operationalizes these principles, allowing students to engage in iterative problem solving and collaborative design in authentic contexts (Prince & Felder (2006)). Education for Sustainable Development (ESD) extends this perspective by emphasizing systems thinking, future-oriented reasoning, and learner agency, encouraging students to consider the societal and environmental impacts of engineering decisions (UNESCO (2017), Wiek et al (2011)). Finally, the CDIO framework (Conceive–Design–Implement–Operate) provides a broader blueprint for engineering curricula that integrate practical, real-world experiences to develop professional competence (Crawley et al (2014)). While CDIO emphasizes general engineering skill development, combining it with SDG and sustainability-focused PjBL extends its reach, positioning students to engage with complex societal challenges early in their undergraduate education.

The conceptual model for this study suggests that the intersection of UN SDG framing, hands-on design-build-test PjBL, and sustainability-focused learning within the second-year undergraduate curriculum may provide a promising context for supporting the development of engineering students. In this framework, students could strengthen both technical problem-solving skills and broader professional capacities, including a sense of responsibility for addressing societal and community challenges. The potential novelty of this approach lies not in any single component, but in the intentional combination of these elements within a curricular stage that has traditionally offered limited opportunities for experiential or sustainability-focused design projects, providing early experiences that may contribute to students' growth as engineers.

Materials and Methods

Course Design

This project was piloted in two sections of 'User-Centred Design,' a required second-year engineering course for electrical, mechanical, and industrial & systems engineering undergraduate students at the University of San Diego. The courses ran for 14 weeks in the spring and fall of 2024, respectively. The course provided students with an introduction to eco-social justice and empathy-centric iterative design. Students were oriented to engineering as a sociotechnical (rather than technocentric) practice (National Academy of Engineering (1991). Leydens, et. al. (2018), Ertas, A. (2018), Gelles & Lord (2021), Chen et. al. (2020), Przechalski, et. al. (2019), Reddy et. al. (2018)), in which engineers must holistically explore and consider the 'socio' elements of an engineering project (environmental, cultural, economic, political, etc.) interlinked with the technical, to design for a sustainable future. Prior to this course, students had only taken a single, more traditional introductory general engineering course. In User-Centred Design, by completing hands-on design projects, students worked to advance environmental resilience and sustainability through innovation, in alignment with the UN SDG. Concurrently, the course emphasized the cultivation of empathy for users, and designing for equitable solutions and just transitions. Students practiced user-centred design by eliciting user requirements, generating alternative designs informed by user feedback, developing low-fidelity prototypes, and evaluating designs from users' perspectives.

These course objectives were primarily operationalized through two collaborative, open-ended design projects, the first lasting five weeks and the second lasting six weeks. The second project is the subject of this paper. The course learning objectives were as follows:

1. Reflect on and communicate about one's own identity and personal experiences (i.e., privilege and disadvantage) in relation to others.
2. Demonstrate empathy for users by describing how user's experiences may be influenced by societal norms around the intersectionality of issues such as race, ethnicity, gender, age, physical ability, immigration status, literacy, and language.
3. Demonstrate familiarity with qualitative research methodologies (e.g., interviews, observation, and immersion) to engage users and identify user issues related to intersectionality.
4. Demonstrate empathy and other mindsets that support a user-centred approach to engineering design.
5. Analyze and design consumer products by applying principles of design.
6. Translate customer needs to product specifications.
7. Develop a plan to complete a design task.
8. Use prototyping techniques and iteration to develop design ideas.
9. Elicit feedback from users to improve designs.
10. Describe and practice attributes of effective teams and team members.
11. Collaborate with people, especially users, throughout a design process to develop user-oriented concepts, products or services.
12. Communicate design solutions to various stakeholders.

The design project that is the subject of this paper addressed learning objectives three through 12. The project comprised 25% of the course grade; 20% was from assignments, 20% was from an exam, 25% was from the first design project (which is not discussed in this paper), and 10% was earned through class participation and professionalism.

Class Participants

Forty-three students participated in the class across the two semesters; 22 in the spring of 2024 (three women and 19 men), and 19 in the fall (six women and 13 men). Most students were still undeclared when enrolled in the class, but would go on to major in electrical engineering, industrial & systems engineering, or integrated engineering. The instructor, a faculty member in mechanical engineering, was experienced in teaching engineering design and had expertise in environmental engineering and sustainability.

Project Design

For their culminating project in the class, student teams were challenged to design a device and/or system to increase the university and local community's sustainability with respect to waste, water, and/or energy. The project culminated in teams creating physical prototypes of their designs that were responsive to user-feedback and needs. The instructor assigned the teams; three students per team.

Before starting the project, the instructor engaged the class in a discussion about sustainability. The student teams were first tasked with coming up with a definition of sustainability. After being given some time to discuss and do background research, each team shared their working definition with the class. Next, the teams were asked to reflect on how they thought the university was doing with respect to sustainability. The instructor engaged the class in a discussion about their perceptions, including highlighting sustainability efforts that the class observed, noticing areas where they felt the university

should be doing more, and how they thought the university was doing as compared with other institutions they were familiar with. They were also directed to the university's Office of Sustainability website, which most were unfamiliar with, but which contained reports about the university's efforts with respect to renewable energy, water, and waste. It was emphasized that the students were not trying to solve the university's sustainability problem with this project; instead, they were targeting a certain 'symptom' of the larger problem with a design that aimed to address a user need related to sustainability within the campus community.

Instructions for each project deliverable were posted on the course website, and the instructor delivered timely mini-lectures at the beginning of class to go over the deliverable expectations. The classes were run workshop-style, with teams working on the project during class and the instructor circulating to check in with the teams and provide them with guidance and constructive critiques of their work.

Deliverables

The project included the following interim and summative deliverables, culminating in a CAD model, physical prototype, presentation and report:

1. D1 Annotated Bibliography—Students were tasked with finding resources (a minimum of three per person) that would educate them on the sustainability issues facing the community. Their writeup had to convey the relevance, accuracy and quality of the work reviewed.
2. D2 Problem Statement—A cohesive overview of relevant community sustainability challenges, including a descriptive title, overview of the identified challenges/need(s), and identification of the primary user(s). Additionally, students were required to detail the functions, objectives, and constraints for the team's identified design challenge.
3. D3 Interviewing, Revised Problem Statement, Design Parameters—Students were required to interview three individuals with first-hand experience and/or knowledge related to the problem identified.
4. D4 Ideation—Including the submission of a morphological chart and at least three different visualized design alternatives (to scale, including dimensions).
5. D5 Design Evaluation—A complete weighted benefit analysis, with each criterion's importance and weighting justified. This deliverable also included a design conclusion and the final design selection.
6. D6 User Feedback Plan—Writeup of usability testing meeting plan to be implemented with a minimum of three potential users.
7. D7 Detailed Computer-Aided Design (CAD) Final Design—A detailed, 3D CAD (i.e., Solidworks) of the final design with multiple viewpoints and dimensions.
8. D8 Final Presentation—A five-minute presentation designed to share the team's problem, final solution/prototype, and PjBL takeaways with the class.
9. D9 Final Report—A final professional report detailing the design project and process, primarily composed of the previous interim written deliverables, including an introduction, methodology, results, discussion, and conclusion.
10. D10 Peer Evaluation—An individually completed form evaluating one's own performance and the performance of each of their team members.

Timeline

The class met twice weekly for 80 minutes in a classroom, with access to a computer lab, makerspace (including 3D printers), and a wood shop. The project spanned 6 weeks, including a class session devoted to students giving final presentations (see project timeline in Table1). Teams continued to

work on the project outside of class in order to keep pace with the deliverable due dates, and had access to the labs and maker spaces during weekday business hours. Outside of class hours devoted to the project varied by team and by week.

Table 1. Design project schedule, by class topic

Class	Class Topic	Deliverables Due
1	Project introduction (design challenge presented)	
2	Problem statement lecture & work time	D1, D2
3	Interviewing lecture, ideation lecture & work time	
4,5	Work time (with instructor consultations)	
6	WBA/user testing + final design lecture	D3, D4
7	Work time (with instructor consultations)	D5, D6
8	Work time (with instructor consultations)	D7: Detailed CAD final design
9	Final presentation + report lecture & work time	
10	Work time (with instructor consultations)	
11	Final presentation + prototype demonstration	D8: Presentation and Prototype Demo
		D9, D10 (due one week after final class)

Grading

The final project grades were a combination of technical achievements (50%) and the final report (50%). The instructor provided the students with rubrics for each assessment. The written report rubric was based on report content (70%), organization and structure (15%), and syntax, mechanics and formatting (15%). Students were provided with detailed instructions for the report and a sample report from a previous semester that was exemplary. The technical achievement was based on the quality (including the level of detail, correct dimensions, etc.) of the CAD model and the prototype. Again, students were provided with past examples to clarify the expected outcomes. Additionally, the instructor provided interim oral feedback to the students to help orient them to the expectations. Following the project, Each student submitted a confidential form to the instructor rating the project contributions of themselves and their team members.

Project Reflection

Upon project completion, the instructor prompted students to individually respond to the following reflection prompts in 200 written words or less:

1. Please describe your most valuable learning takeaways from working on this project.
2. What challenges did you personally encounter working on this project, and how did you overcome them?
3. Please define/describe ‘sustainability’ using your own words. (2-4 sentences)

Analysis

The student reflections were analyzed using an inductive thematic analysis (Clarke et.al. (2015)) to explore learning outcomes and perceptions of the project. Reflections were collected using structured prompts, but responses were analyzed in aggregate to allow themes to emerge naturally. Analysis followed a multi-step process: responses were first read multiple times to gain familiarity with the data; initial codes were generated to capture key ideas and recurring concepts; preliminary themes were then identified by grouping related codes, and student responses were mapped to these themes. The themes were iteratively refined as coding progressed to ensure they accurately reflected the data. In this paper, illustrative student quotes are presented using pseudonyms to preserve anonymity.

Results

Sample Project Technical Outcomes

Because each student team could identify the community sustainability need that their project would address, each project was different. In order to provide a sense of the wide range of design and prototype outcomes, some examples included: 1) a ‘smart’ compost bin with sensors and a scale that could weigh the amount of food-waste being added, 2) a large-scale campus food garden design, showcased as a detailed, scaled model made out of balsa wood and miniature 3D-printed pieces, and 3) a refillable/reusable dry erase marker and eraser set for use in classrooms (in-place of plastic, disposable markers and Styrofoam-based erasers commonly used).

Student Reflections

The primary identified themes from the student reflections included: 1. Deepened Community Connection, and 2. Moving from ‘They’ to ‘We.’ Identified themes and sub-themes are listed in Table 2. The following sections describe the salient findings from each theme and sub-theme.

Table 2. Themes and Sub-Themes.

	Theme	Sub-Theme
1.	Deepened Community Connection	i. Increased Community Understanding ii. Applied Critical Thinking
2.	Moving From ‘They’ to ‘We’	i. Shift in Perspective ii. Craving Involvement iii. Let’s Do More

Deepened Community Connection

Following project completion, students described a deepened sense of connection to their community. This deepened connection was expressed both in terms of an increased understanding of the community’s sustainability efforts, and the ability to apply their own critical thinking to assess those efforts.

Increased Community Understanding

The students articulated increased understandings of sustainability efforts on campus, and about the university’s commitment to sustainability. For some, what they learned challenged their previous assumptions. For example, Sarah “learned that [the university] is more committed to sustainability than [she] initially assumed” and Debra “learned that [the university] does actually care about sustainability.” They cited “having no idea about” initiatives like “installing solar panels,

incorporating food waste systems to reduce waste,” and “efficient irrigation and watering systems” as causes of these previous misconceptions. These efforts were a surprise to Debra who, “honestly, prior to this project...didn’t know [the campus] made efforts to be more sustainable.” Similar sentiments were expressed by a number of other students, including Adam, who learned that the university “has a substantial sustainability program” and before he “had no clue how much work the school was putting into efforts to reduce its consumption/impact.”

Other students did have some concept of sustainability efforts, but their perceptions changed as they learned more. Andre was familiar with the solar panels and composting efforts, but he *“learned a lot more about the water conservation systems they use on campus from [interviewing] the office of sustainability.”* Derek expected the water usage to be *“really low.”* He *“got proved otherwise,”* and *“didn’t know that they didn’t have any type of rainwater vessels on campus.”* For Derek, his increased understanding *“was concerning since [he sees] how green [the] grass is, meaning that [the] water usage...is very high.”*

Applied Critical Thinking

Students critiqued aspects of campus sustainability, including messaging, accessibility of data, and bureaucratic processes. For example, Tammy learned about an existing composting program but noted she *“would have never known [about it] before [she] interviewed the director.”* Adam observed that *“data on the office of sustainability website was several years old, and some of the programs listed in it had been shut down since,”* suggesting more timely updates. Other students noted aesthetic restrictions and departmental barriers limiting sustainability implementation. Mason summarized: *“Overall, [the school] is on the right track but must intensify its efforts and involve the entire campus community to achieve its sustainability objectives fully.”* Some students suggested practical improvements, such as adding compost bins or simplifying policy processes to enable faster action.

Moving From ‘They’ to ‘We’

The students articulated a shift in thinking about campus and community sustainability as a *‘they’* issue (meaning the students were on the outside of the issue looking in and expecting others to engage with it), to a *‘we’* issue (where they were the involved actors). For example, one team prototyped a smart compost bin, and over the course of the project they became passionate about implementing their bins around campus. They submitted a proposal to the campus outlining their idea, received funding, and continued to work on bringing their vision to fruition after completing the course.

Shift in Perspective

The shift from *‘they’* to *‘we’* thinking varied from student to student. Nate noted the project changed his view on solar energy, and Tim described being *“more conscious of [his] sustainability efforts”* through small personal actions. Sarah reflected: *“These efforts inspired me to think more critically about how sustainability can be integrated into engineering projects and everyday practices. This knowledge has encouraged me to explore ways to incorporate sustainability into my own designs and projects in meaningful, practical ways.”* Omar emphasized the applicability of sustainability to engineering: *“It is really cool how as an engineer, we can make interesting products that truly help the environment of our world.”* Jeff highlighted broader awareness: *“[I] learned that it involves a lot more than [I] initially thought...to the point where it can be an entire lifestyle.”*

Craving Involvement

Moving from a ‘they’ to ‘we’ perspective also entailed articulations of increased self-ownership of and craving involvement in community sustainability efforts. In Greg’s words, he felt that the school was “*excelling at having a strong drive for sustainability, [but that] the only con is the lack of student involvement.*” He identified a root cause as the lack of available information, which “*leads to a majority of students not practicing sustainability or completely disinterested in the idea.*” He felt that the solution was “*making sustainability more known and realising the effects for people... [would] change the mindset around sustainability,*” and this would “open the way for all students to participate and [have] more students step up to find better ways to practice sustainability.”

Greg’s sentiments were shared by a number of students. For example, Tammy and Jane echoed this need, emphasizing that existing programs were not well-known among students. Mason recommended more transparency and investment in student and faculty engagement. Peter proposed streamlining policy processes to enable faster action and motivate student initiative.

Let’s Do More

Students articulated a sense of collective potential and responsibility to act. Jack connected his takeaways to engineering and environmental stewardship: “*Working with others who cared about the planet made me realize that engineering can make a positive impact... Seeing the positive results of our work made me want to keep helping the Earth in any way I can.*” Jeff highlighted potential ripple effects: “*[The campus] can inspire other far-larger campuses to make some changes; and the effects of those changes will definitely be felt.*” Eric reflected on leveraging campus resources for broader sustainability impact. Across students, the reflections captured both inspiration and recognition of practical opportunities for action.

Discussion

This project was successful, both in terms of addressing the necessary course outcomes as well as providing a hands-on PjBL experience for undergraduate engineering students that cultivated their preparedness to advance solutions to the UN SDG. Bonus outcomes from the project included students’ self-described deepened sense of connection to their community and shift in thinking of sustainability as a ‘they’ issue to a ‘we’ call-to-action. As such, these findings advance the literature on how to integrate UN SDG learning opportunities into undergraduate engineering education as well as options for integrating hands-on engineering design PjBL experiences into the middle university years that are often void of design-build-test projects. While prior studies have explored elements of UN SDG integration, sustainability-focused learning, and hands-on PjBL, the intersection of these areas, especially within the context of second-year undergraduate engineering education, is novel. By exploring this convergence, the study offers an example of how other engineering educators might embed analogous experiences into their students’ second or third university years. These findings are limited, from project implementation in two course offerings, with 43 students.

Although this project was piloted across two semesters of a second-year introductory engineering design course, it would also be appropriate for implementation in a more advanced engineering design or sustainability elective course. The project design is highly adaptable, and could easily be scaled by toggling the level of expectations for project deliverables. For example, designs could range from simple conceptual sketches to scaled, detailed CAD renderings (as were required in this project piloting). Similarly, prototypes could be representative of the critical function(s) only and built using rudimentary materials or require more advanced 3D-printing, manufacturing, and/or machining

techniques. Similar toggling and requiring of more or fewer design iterations could allow for the project to fit into either a condensed (such as two weeks) or extended (such as a full semester or year) time frame.

Because this project challenged students to design a device that would advance the community's sustainability with respect to waste, water, and/or energy, it explicitly addressed four of the 17 UN SDG (those dealing with water, clean energy, sustainable communities, and responsible consumption and production). However, each team got to identify the community sustainability need that their project would address, and therefore each project was different. Depending on the chosen design challenge addressed by a given team, their project could (and often did) address additional SDG goals. For example, the smart composting bin project previously described in this paper was designed to reduce food waste and provide compost for community gardens to grow food. That project therefore also addressed SDG 2, Zero Hunger, which is stated to “end hunger, achieve food security and improved nutrition and promote sustainable agriculture.” The varied nature of the projects and their diverse means of addressing of the UN SDG provided rich opportunities for class discussions and for the students to learn about the other global sustainability issues (and possible solutions) from their classmates.

Taken together, these findings illustrate how intentionally combining UN SDG framing, hands-on PjBL, and sustainability-focused learning aligns with the goals of the conceptual model to support the development of engineering students. By situating the project within a second-year course, a curricular stage often lacking design-build-test opportunities, students were able to gain additional experience with the full cycle of experiential learning (Kolb (1984)). The findings from this study resonate with CDIO principles by illustrating the potential of early, hands-on design experiences to support students' development as engineers. The UN SDG and sustainability framing additionally provided an opportunity to cultivate these burgeoning engineers' awareness of societal and community responsibility.

Conclusions

A hands-on, design-build-test PjBL experience that addressed four of the 17 UN SDG was developed and piloted with 43 students in two second-year required engineering courses. Student teams were challenged to design and prototype a device to increase their community's sustainability with respect to waste, water, and/or energy. Findings from a thematic analysis of post-project student reflections were favourable, and indicated that students experienced a deepened connection to their community and an increased sense of personal responsibility to advance the community's sustainability. These findings advance the literature on how to integrate UN SDG learning opportunities into undergraduate engineering education to contribute to the preparation of globally responsible 21st century engineers. Additionally, the project provided an option for integrating hands-on engineering design PjBL experiences into the middle university years that are often missing design-build-test projects. The presentation of the course and project design included suggestions for how to scale and adapt the project for implementation in a range of other engineering education settings.

Practically, the project demonstrates that SDG-aligned, sustainability-focused design experiences can be embedded within required middle-year courses while maintaining core technical learning outcomes. The approach offers instructors a flexible model that can be adapted in scope, duration, and technical complexity. At a policy level, the findings support broader calls from accreditation bodies and engineering organizations to prepare graduates capable of addressing complex societal challenges, suggesting that such preparation can begin earlier and more intentionally within the curriculum.

Future iterations of the course could place greater emphasis on helping students more clearly connect their design decisions to specific UN SDG targets and to consider trade-offs between environmental, social, and technical factors. Expanding community partnerships and creating pathways for real-world implementation could further enhance authenticity and impact. Additionally, extending this approach across multiple years of the curriculum may further reinforce the development of engineers who are both technically capable and socially responsive.

Funding

This research received no external funding.

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the University of San Diego (IRB-2023383).

Conflicts of Interest

The author declares no conflicts of interest.

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