Infusion of Design Justice Principles into an Undergraduate Capstone Project Course Sequence

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Introduction

This paper presents the inclusion of Design Justice principles into a multidisciplinary engineering curriculum, specifically focusing on a capstone project course sequence. Per [1], "Design justice rethinks design processes, centers people who are normally marginalized by design, and uses collaborative, creative practices to address the deepest challenges our communities face."

Currently, the undergraduate curriculum at Elizabethtown College features significant design coursework in 6 out of 8 semesters, starting with Introduction to Engineering and culminating with a three-semester entrepreneurially-minded capstone sequence. While the infusion of Design Justice into our curriculum involves multiple stages, this paper is focused specifically on the capstone sequence [2].

In previous versions of the capstone sequence, we used Pugh's Product Design Specifications (PDS) as a central tool for design [3]. In recent iterations, we have used an updated model, infusing principles from the Design Justice framework into Pugh's model [4]. In this paper, we analyze the impact of this infusion on student work. We review final reports from capstone courses, analyzing the depth and quality of Design Justice-related content present, before and after the changes to the course sequence.

Background: Design justice framework

Design Justice advocates for designers to interrogate how benefits and burdens in technology design are disseminated. The framework also calls for distributing benefits and burdens equitably [5], [6]. Emerging from the Allied Media Conference in 2014, Design Justice's foundations are in Black Feminist scholarship, including intersectionality [7] and the Matrix of Domination [8]. Design justice also includes a set of principles that support justice-based design work and focus on empowering communities through design. Recent work in engineering has examined engineering design in the context of design justice. Varying works have explored how justice and equity are embedded in engineering design [9], [10]. Conferences, including ASME IDETC-CIE's Design Theory and Methodology track, have had further engagement with design justice, including a workshop and dedicated session for design justice in 2023 and a special session on design justice in 2024 (e.g., [11], [12]). These additions to the engineering design community signal an increasing dedication and desire in the community to understand, investigate, and engage with design justice in engineering.

Though work incorporating design justice into engineering design has begun in the past few years, engineering education has long been calling for social justice to be further incorporated into engineering education and design [13], [14]. Recent works have investigating design justice in the context of engineering education have focused on how design courses engage with design justice [15], how social, ethical, and policy considerations are incorporated by instructors [16], and how instructors can be supported to embed design justice into their courses and build communities around design justice in design education [11]. To realize goals of embedding greater consideration of design justice in engineering education, these works emphasize that we can shift engineering education including supporting community-building, empowering people in change movements, and working with instructors and other university members to get buy-in and prioritization around design justice [16]. Fostering this change also needs to be approachable for instructors and support larger visions around embedding design justice [11], [17]. The Accreditation Board for Engineering and Technology (ABET) have demonstrated support for equity and justice considerations in engineering education with an accreditation criterion centered around embedding context related to diversity, equity, and inclusion for future engineers to translate into their work after graduation [18]. This accreditation criteria and other works calling for greater inclusion of design justice in engineering education emphasize growing movements for engineering education evolution that can be fostered and supported through collaboration with departments, schools, and leadership to reimagine engineering education from assignments to curriculum change.

Institutional background

Elizabethtown College, located in southeastern Pennsylvania, is a small liberal arts institution with around 2,000 students. Situated in a rural area, the college offers a primarily residential, undergraduate experience focused on community engagement, as reflected in its motto, "Educate for Service."

The Department of Engineering and Physics is one of the largest at the college, offering an ABET-accredited Bachelor of Science in Engineering with concentrations in Civil, Mechanical, Electrical, Mechatronics, Environmental, Industrial, Computer, and Biomedical Engineering. With an incoming class of around 70 students, the department is growing and serves a diverse population, including many first-generation students and student-athletes. The department is known for its adaptability and commitment to continuous improvement, making it well-suited for adopting innovative educational approaches like Design Justice.

Furthermore, the Engineering program is a Kern Entrepreneurial Engineering Network (KEEN) partner institution. KEEN fosters the development of an entrepreneurial mindset (EM) among engineering students, emphasizing creativity, connection, and creating value in real-world contexts. Students are encouraged to approach challenges with a mindset that values not only technical expertise but also social impact, resilience, and adaptability—key concepts that align well with the principles of design justice. By infusing and intertwining both design justice principles and the entrepreneurial mindset into our capstone coursework, we aim to empower students to design solutions that are not only technically sound but also entrepreneurial, ethically responsible, and inclusive, ensuring their work serves the broader community.

Project course sequence

The engineering program includes a comprehensive project sequence across six of the eight semesters, immersing students in the engineering design process with an emphasis on collaboration, community service, and real-world problem-solving. In the first year, students are introduced to basic engineering principles through structured projects in an introductory course, beginning to engage with the design process by identifying problems and exploring solutions.

In the second year, students work on community-based projects, applying their knowledge to address local or regional needs. This experience helps them understand the societal impact of engineering and fosters a sense of responsibility to the communities they serve.

In EGR 301 Engineering Design and Junior Project, offered in the junior year, students work in teams to dive deeper into the design process, gaining a comprehensive understanding from problem identification to solution development. The course also introduces design justice principles, emphasizing equity, inclusivity, and social justice in design. The semester ends with a budget pitch, simulating real-world project initiation.

In the senior year, EGR 401 and 402 (Senior Project I and II) focus on analysis, detailed design, fabrication, and testing. Design reviews help students justify their design choices, considering material, cost, and broader impacts, while simulating real-world decision-making processes.

Historically, the department has used Stuart Pugh's Total Design Methodology, with the Product Design Specifications (PDS) serving as a central tool. This structured framework laid a strong foundation for integrating Design Justice into the curriculum, as further explained by [2].

Infusion of design justice into the curriculum

The introduction of design justice principles into the capstone sequence was a natural extension of the department's commitment to continuous improvement, service-oriented education, and the entrepreneurial mindset. Several factors made the engineering program an ideal environment for this infusion. First, the values of design justice, which prioritize inclusivity, equity, and address the needs of marginalized communities, align closely with the institutional mission of Elizabethtown College. The college's emphasis on education for service and its commitment to social responsibility provided a solid foundation for introducing these principles into the curriculum. Second, the Engineering program's engagement with KEEN and its focus on developing an entrepreneurial mindset (EM) complement the values of design justice, particularly in fostering creativity and collaboration. Additionally, EM's emphasis on creating value aligns with design justice's commitment to inclusivity and addressing the needs of marginalized communities.

Moreover, the nimble nature of the department allowed for easier adaptation of new teaching strategies, such as the integration of design justice, into the existing project sequence. The department's ongoing commitment to refining its teaching practices and the Pugh PDS framework also facilitated the introduction of these concepts, providing an opportunity to strengthen existing structures rather than starting from scratch.

The integration of design justice principles was rolled out in stages. Initially, the infusion began with workshops for senior students in EGR 401/402 (Fall 2023 and Spring 2024). These workshops focused on providing students with the tools to consider justice, equity, and community impact in their design processes. The senior-level courses were an ideal platform for introducing these ideas, as students were already engaging with complex design problems and were ready to explore the broader implications of their work.

Following this initial introduction, design justice principles were incorporated into the junior-year course, EGR 301 (Engineering Design and Junior Project), during the Spring 2024 semester. In this course, students participated in two dedicated sessions—one in February and another in

April—that focused on embedding design justice into the design process. These sessions emphasized the importance of considering the social and ethical implications of design decisions and encouraged students to reflect on how their projects could better serve underserved communities.

The impact of these workshops and sessions have carried over as these students are currently in EGR 401/402 Fall 2024 and Spring 2025, where students continue to carry forward the principles of design justice into their projects. These students applied the concepts they learned to develop solutions that were more inclusive, equitable, and socially responsible, thereby solidifying the role of design justice in the department's educational framework.

Methods

The researchers analyzed 9 reports from Spring 2023 (EGR301) and 8 from Spring 2024 (EGR402). Each of the student reports were coded by the researchers by sections of the report, that included: Revisions from Previous Reports/Introduction, Solution Level Product Design Specifications, Conceptual Design Process, Initial Detailed Design, Plan for Next Year, and Tentative Budget. A few reports had a Project Management section, though due to either none or one mention of a PDS term in that section across reports, the researchers determined that it was not worth including in the final analysis. Additionally, some of the Spring 2023 reports included sections that discussed Relevant Codes and Standards and Social, Ethical, and Environmental Issues, which complemented the earlier sections of the report, and thus were included in the coding. The engineering analysis section was omitted as well because it consisted of calculations and technical details that were not relevant to the scope of the study.

Each of these sections were coded using the relevant PDS document that the students had access to that semester. For Spring 2024, this was the original, unedited Pugh version of the PDS, and for Spring 2023, it was the first revision of the PDS by the researchers. The researchers recorded all the PDS terms that the students mentioned in their writing, and then additionally counted the number of implicit versus explicit mentions of the terms in a section. For example, if a student explicitly wrote out "PDS" or referenced the tool when listing a term, then that would count as an explicit mention. An example of an explicit mention is provided below:

> *Based on our PDS, our team has decided to move forward with the idea of attaching a generator to a stationary bike.*

Alternatively, if the student discussed ideas related to a term, such as discussing the environmental impact without explicitly stating "Environmental Impact" in reference to the PDS, then that would be an implicit mention. An example is provided below:

> *Since we will be recycling more plastic, less will show up in landfills which would potentially leak into the environment. Reusing plastic saves the energy cost to destroy it, which in the long run, lowers the emissions caused by burning plastics.*

Finally, student reports were rated using two independent scales for depth and social engagement (similar to [10]). The scale included four levels: no, low, medium, and high. Each researcher independently coded depth and social engagement for each section of each report for all eight of the Spring 2024 reports. After discussing differences between the coded segments, resolving discrepancies, and establishing that the rating method was consistent across all reports, the researchers split the Spring 2023 reports. Each researcher coded these separately since these reports were very extensive, ranging from 31 to 82 single spaced pages, with average being around 51 pages single spaced.

Results

The average number of PDS per report section can be found in Figure 1. The sections of Solution-Level PDS had the highest average across both semesters.

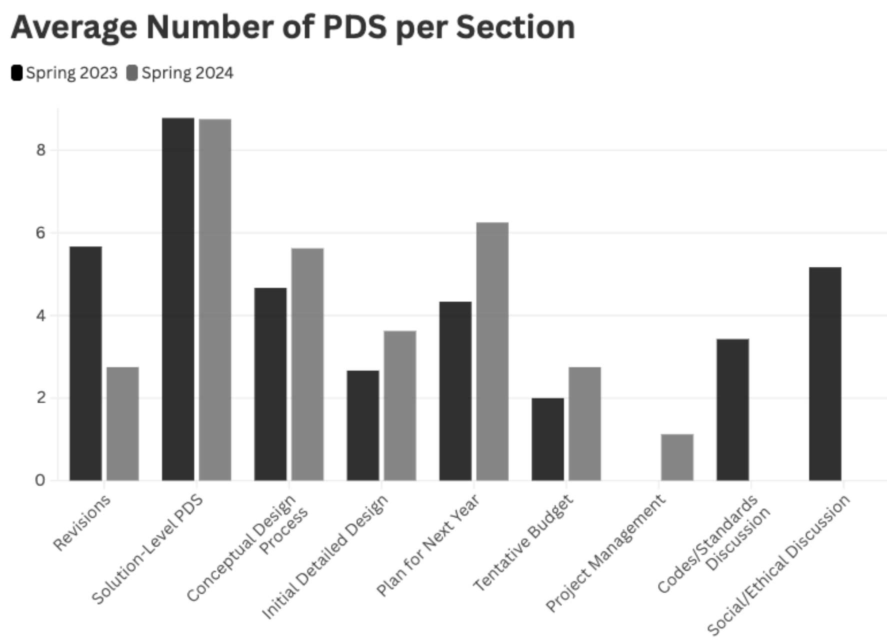

Figure 1. Spring 2023 and Spring 2024 average number of product design specifications per final report sections

Figure 2 shows the average social engagement score for each report section. Across all sections found in both reports, social engagement was higher in the Spring 2024 reports. PDS in the Solution-Level section increased by 40%, Revisions by 20%, and Initial Detailed Design by 28%. The score for Conceptual Design Process increased from 0.11 in Spring 2023 to 1.5 in Spring 2024, and Plan for Next Year increased from 0.25 to 1.38.

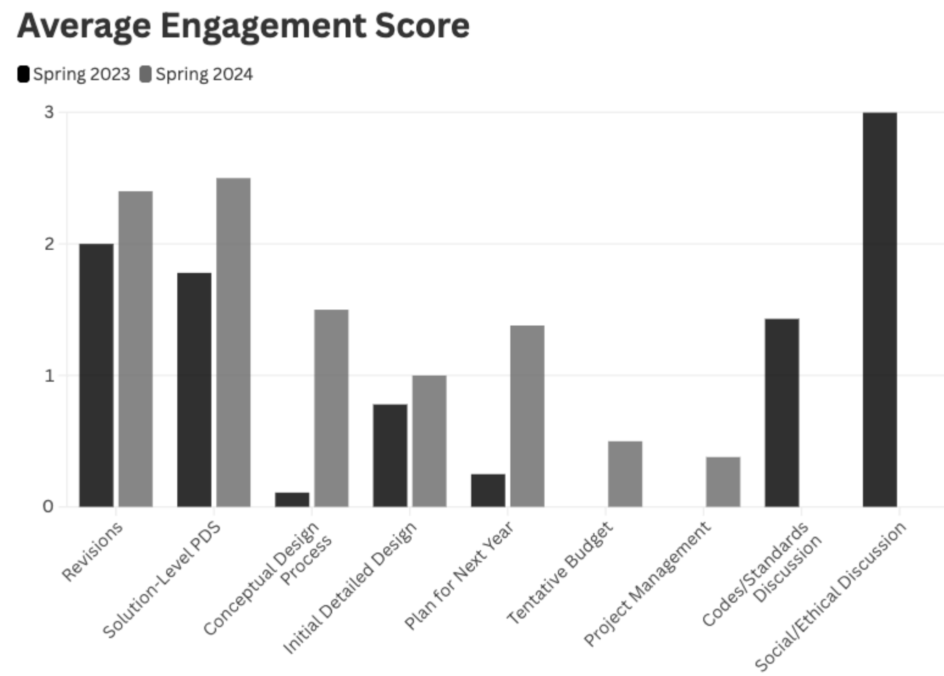

Figure 2. Social engagement score for each semester report

The Tentative Budget and Project Management sections scored the lowest, with average engagement scores of 0.5, and 0.38, respectively, highlighting their logistical nature. In contrast, the Discussion of Social, Ethical, and Environmental Issues section scored the highest in the 2024 reports, which is expected given its direct emphasis on these topics.

For both reports, the PDS in the Revisions and Solution-Level sections also consistently received some of the highest social engagement scores. This could indicate that instructors encouraged students to address social and environmental issues during revisions, prompting them to reflect on issues they might have otherwise overlooked.

The average depth scores for the Spring 2024 reports were overall higher for the more design and PDS based sections of the reports, such as Initial Detailed Design and Solution-level-PDS, whereas the Spring 2023 reports scored higher in depth for Revisions and Plan for Next Year. This is an interesting trend as the Spring 2023 students were more detailed in the sections that pertained to past and future work, rather than that semester's work. This could indicate a broader perspective when it comes to the long-lasting impact of the project and the product, and thoughtful considerations of timescales. However, they also included separate discussion sections as well, which might compensate for the lower scores in the other sections (Figure 3).

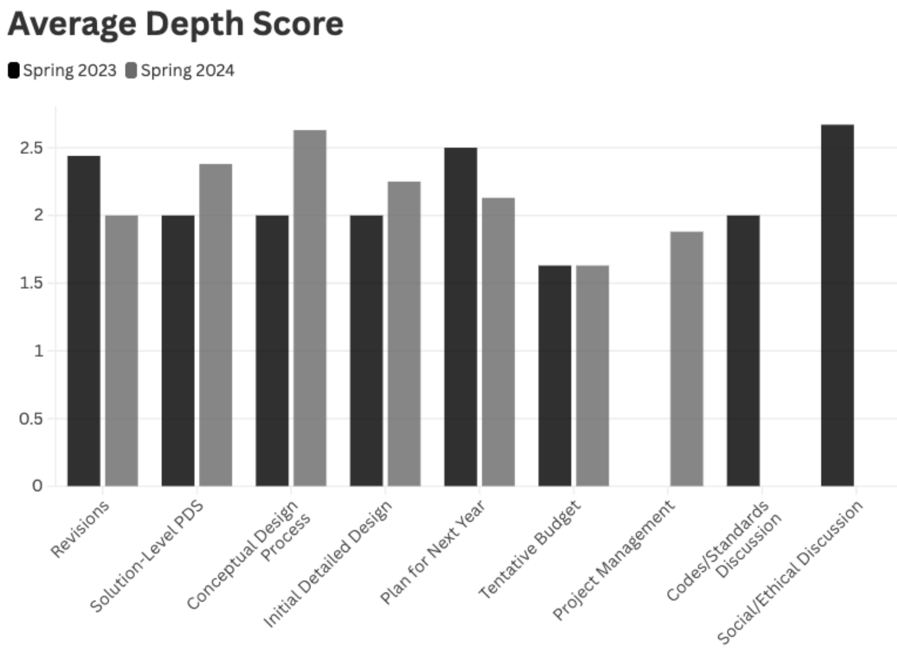

Figure 3. Average depth of product design specifications for Spring 2023 and 2024

For the Spring 2023 reports, the Discussion of Social, Ethical, and Environmental Issues section depth scored the highest, which shows that students were actively considering the broader implications of their projects.

On average, the Solution-Level PDS had the most explicit mentions (Figure 4), with 1.22 in Spring 2023 and 2.5 in Spring 2024. This is not surprising, as the section directly addresses the PDS tool. The Spring 2023 reports had more explicit mentions in the Revisions, Conceptual Design Process, and Plan for Next Year categories. Across both batches of reports, explicit mentions were generally rare, which is why the averages are either low or 0.

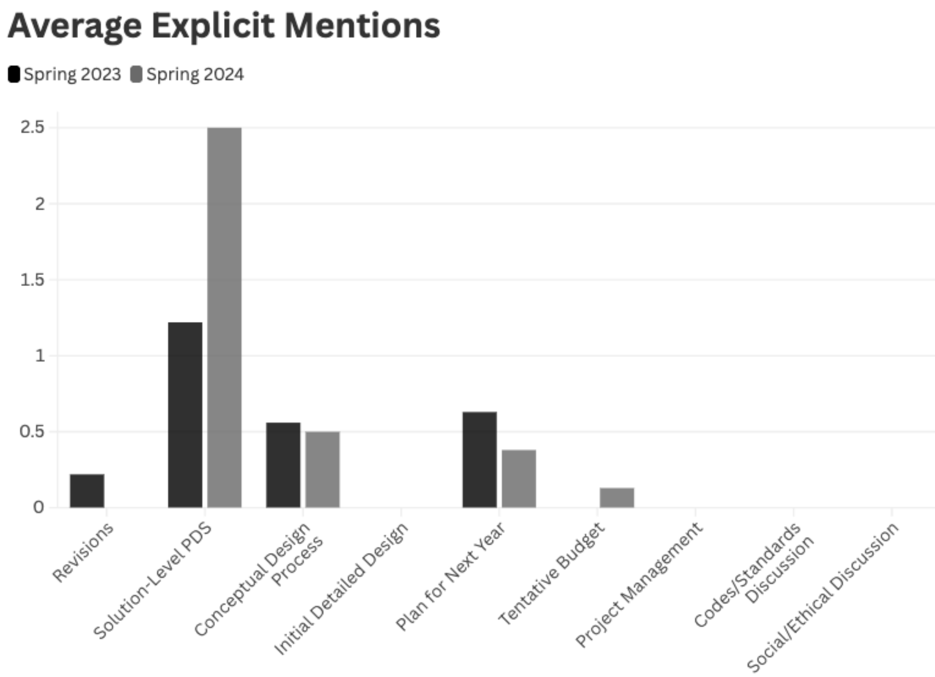

Figure 4. Average explicit mentions in each report section of both Spring 2023 and Spring 2024 reports

Similar to explicit mentions, the section with the most implicit mentions for both sets of reports was the Solution-Level PDS section. This makes sense as this is the section that explicitly asks the students to consider the PDS terms. This section prompt is likely to result in the most implicit and explicit mentions, which emphasizes how the incorporation of the PDS into the section header encourages students to consider more engineering design factors. This can be seen in Figure 5.

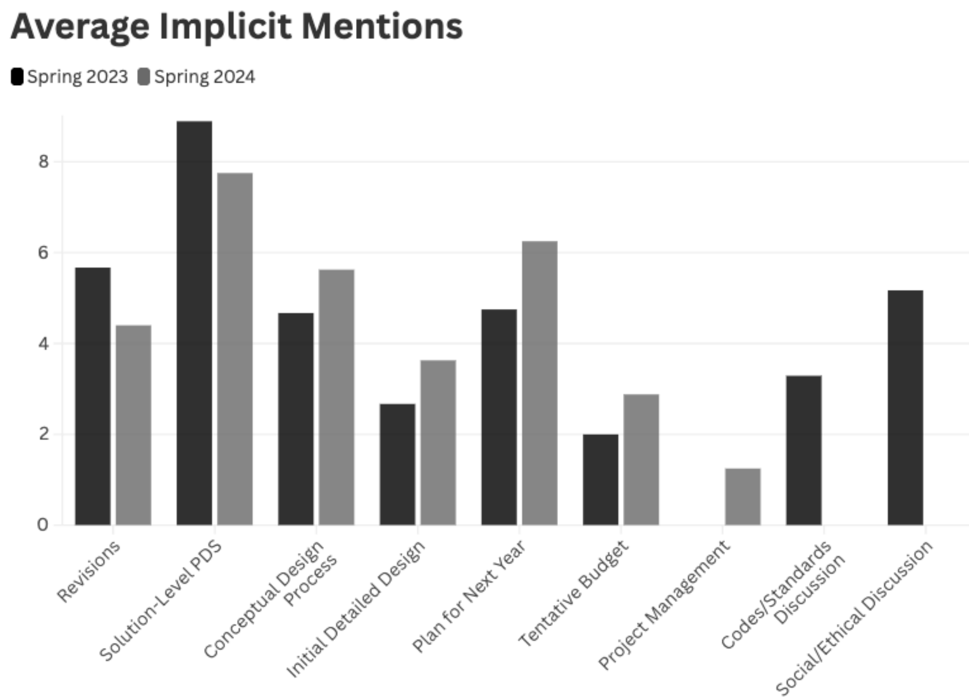

Figure 5. Implicit mentions within Spring 2023 and Spring 2024 reports

Figures 6 and Table 1 illustrate the PDS terms that were most prevalent in each of the different sections of the report. The number of mentions of each PDS term for a particular section of a report were counted, and the term or terms with the highest frequency across all sections were noted. Figure 6 notes how many times a PDS term was considered one of these high frequency terms across all reports for a certain semester. For example, the PDS term Safety Measures was considered a high frequency term for 3 reports from Spring 2023 and 2 reports from Spring 2024, and this is across all sections in these reports. Table 1 shows the highest frequency terms for each section individually across all reports for both semesters.

Looking at these results, customer, safety, size, and target product cost emerge as the most frequent terms across all reports in both years, which indicates that these terms are at the forefront of the students' minds. These are very promising results, as with customer and safety being two of these high frequency terms, the students are really thinking about the consumer and their wellbeing over other factors. Target product cost, while it does include consideration for the finances of the production team, also considers the consumer's budget, and whether or not the product will be affordable for them. Size was an unexpected high frequency term, but it could indicate that students are prioritizing feasibility of manufacturing and production. This makes sense, as they are students, and are limited by facilities, experience, budget, and time, and the size of the product can drastically change the amount of funding or manpower needed to complete a project.

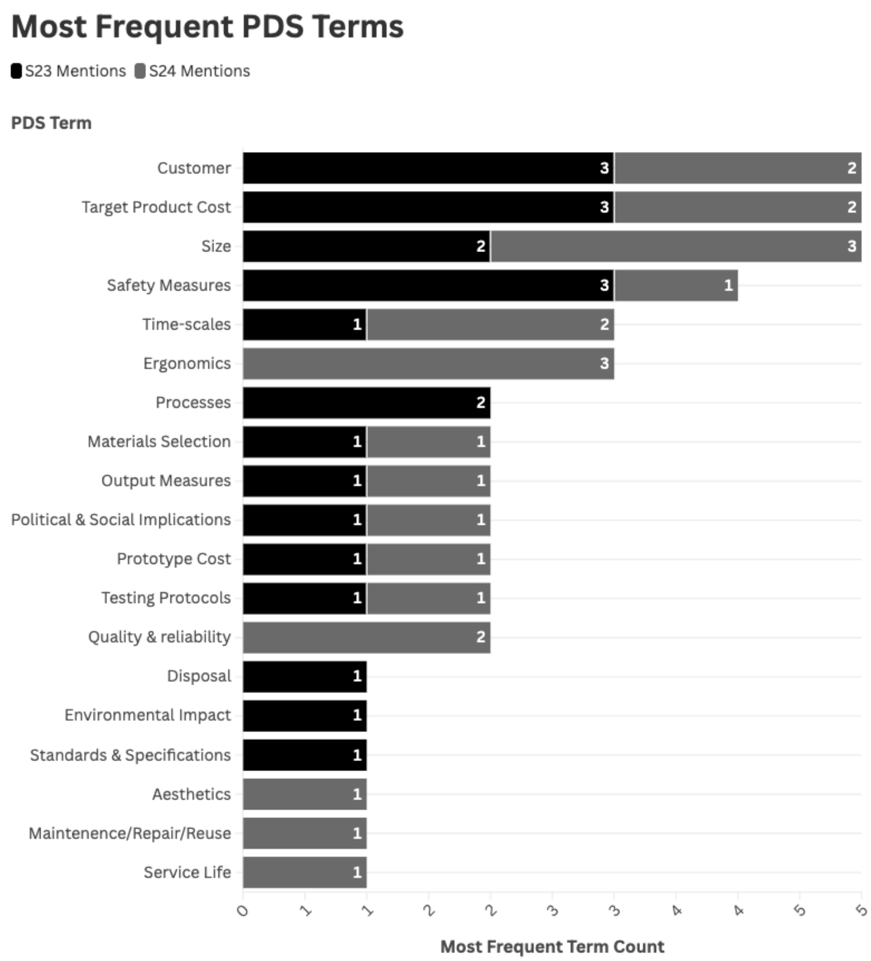

Figure 6. Terms most prevalently used in the Product Design Specifications for Spring 2023 and 2024

Table 1. Most Frequent PDS Terms per section

Section Name	Spring 2023	Spring 2024	Both
Revisions from Reports	product affordability/access (target product cost)	political/social implications	customer
Solution-Level Product Design Specifications	customer, output measures	aesthetics, ergonomics, maintenance/repair /reuse, service life, size	safety measures
Conceptual Design Process	Product affordability/access (target product cost), safety measures	customer, ergonomics, materials selection	size
Initial Detailed Design	customer, materials selection, processes	ergonomics	size
Plan For Next Year	processes	quality/reliability	time-scales, testing protocols
Tentative Budget	N/A	N/A	prototype cost, product affordability/access (target product cost)
Project Management	N/A	time-scales, quality/reliability	N/A
Codes/Standards Discussion	Standards/Specifications, safety measures	N/A	N/A
Social/Ethical Discussion	Environmental impact, political/social implications, disposal	N/A	N/A

Students were also asked to include a PDS in the Appendix section of their reports. For the Spring 2023 reports, the following PDS terms appeared in all appendices: aesthetics, ergonomics, maintenance/repair/reuse, safety measures, service life, and size. Meanwhile, for the 2024 reports, product affordability/access (target product cost) appeared in all reports and maintenance/repair/reuse, materials selection, output measures, and safety measures appeared in 7 out of 8 reports. These findings are summarized in Table 2.

Table 2. Most Frequent Terms in PDS Appendix

Reports	Most Frequent Terms	Avg Frequency per Report
Spring 2023	Aesthetics Ergonomics Maintenance/repair/reuse Safety Measures Service Life Size	1
Spring 2024	Product affordability/access (target product cost)	1
	Maintenance/repair/reuse Materials Selection Output Measures Safety Measures	0.87

In terms of the least frequent terms, operation environment was found in 1 out 9 Spring 2023 reports, and prototype cost and production life span appeared in 2 out 9 Spring 2023 reports. In the 2024 reports, the terms with the fewest mentions were company constraints, environment, market constraints, packaging, shelf-life, and standards/specifications, each appearing in 1 out of 8 reports. These findings are summarized in Table 3.

Table 3: Least Frequent Terms in PDS Appendix

Reports	Least Frequent Terms	Average Frequency of Mentions per Report
Spring 2023	Operation environment	0.11
	Prototype Cost Production Life Span	0.22
Spring 2024	Company Constraints Environment Market Constraints Packaging Shelf-Life Standards/Specifications	0.13

The political and social implications were mentioned with similar frequency in both sets of reports, with an average score of 0.67 in Spring 2023 and 0.63 in Spring 2024. On the other hand, environmental impact was mentioned less often in Spring 2023 reports, with an average score of 0.33, but rose to 0.75 in the Spring 2024 reports. This indicates a stronger emphasis on environmental considerations in the more recent reports. The full breakdown of all PDS terms in the appendices and their average frequency per report can be seen in Figures 7 and 8.

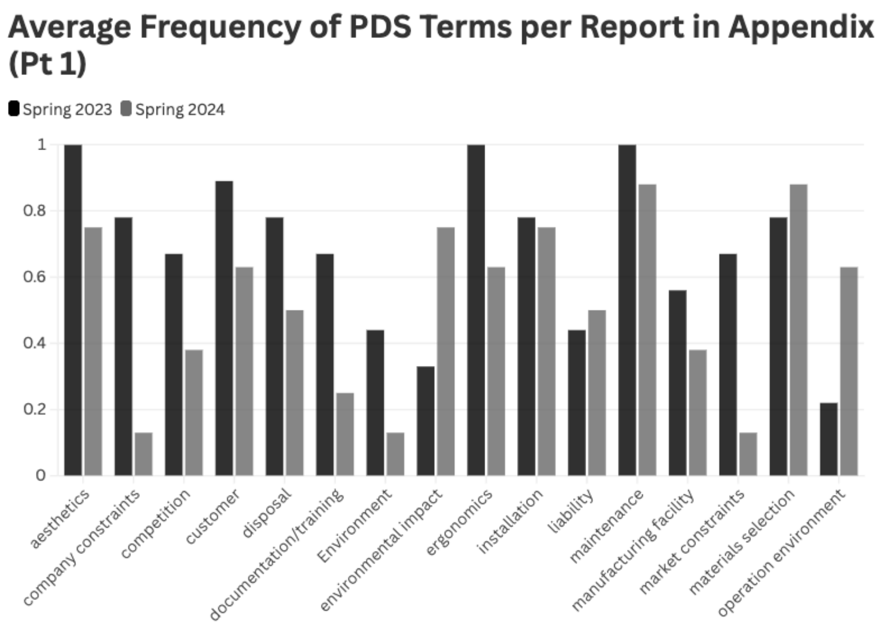

Figure 7. Average frequency of product design specifications per report I

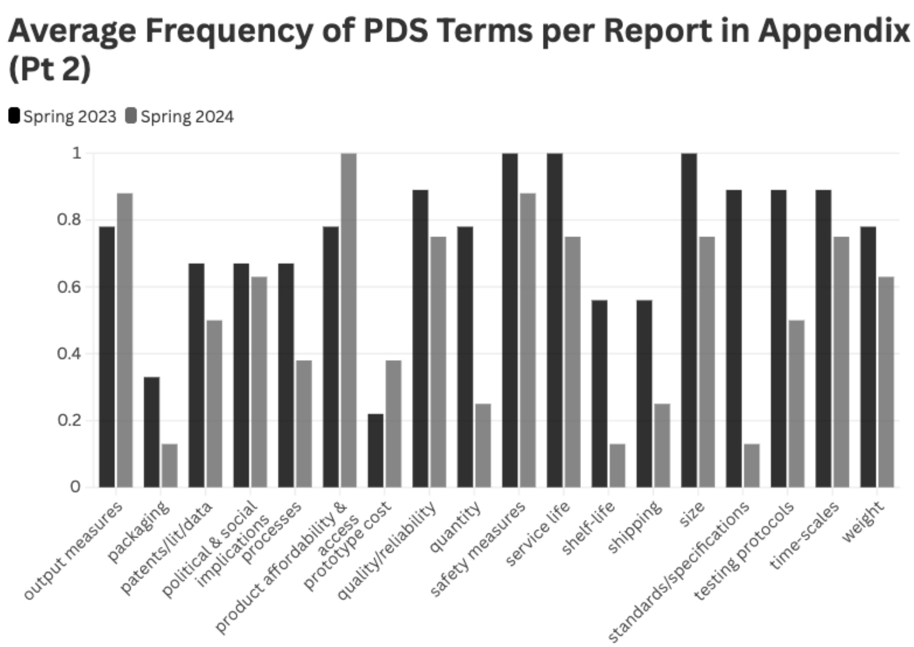

Figure 8. Average frequency of product design specifications per report II

Discussion and Conclusions

This study explored the integration of design justice principles into an undergraduate engineering capstone sequence and assessed their impact on students' design work, focusing on social engagement, depth, and community impact. Our findings indicate that the infusion of design justice principles significantly influenced students' ability to consider equity, inclusivity, and social responsibility in their designs.

The Spring 2024 reports showed clear improvements over the previous year, particularly in sections such as Solution-Level Product Design Specifications (PDS), Conceptual Design Process, and Initial Detailed Design. Students in 2024 demonstrated increased engagement with social and ethical issues, reflecting a heightened awareness of the impact their designs could have on marginalized communities and the environment. This aligns with previous research emphasizing the importance of incorporating social, ethical, and environmental considerations in engineering education [16], [17].

Notably, the Spring 2024 reports showed a significant increase in attention to environmental impact, rising from 0.33 to 0.75 on the depth scale. This demonstrates a growing recognition of sustainability within engineering design. The increased focus on topics like political/social implications and product affordability/access also indicates that design justice principles encouraged students to think beyond technical aspects and consider the broader societal impacts of their work.

While logistical sections like the tentative budget and project management continued to score lower in both years, there was an overall improvement in the engagement with social and ethical issues within more design-focused sections. This suggests that while technical considerations remain central, the infusion of design justice principles prompted students to adopt a more holistic approach to problem-solving.

The explicit and implicit mentions of PDS terms such as customer, safety measures, and product affordability/access suggest that students were increasingly aware of the ethical dimensions of their designs. These terms indicate a shift toward a more user-centered and socially responsible design process, with safety being a consistent priority across both years.

The integration of design justice principles through revised PDS not only enhanced students' ability to address social and ethical considerations but also strengthened their entrepreneurial mindset (EM). By encouraging students to think critically about their stakeholders and the constraints of their designs, they were able to apply the KEEN 3 C's—curiosity, connection, and creating value—within a justice-oriented framework. Students developed a deeper understanding of how to be curious about the lives of others, connect the technical aspects of design to social constraints, and ultimately create better designs with greater value.

Overall, the integration of design justice principles had a positive impact on students' design work, though further efforts are needed to ensure consistent application across all sections of their reports. Expanding design justice content earlier in the capstone sequence and continuing to provide students with tools to engage critically with these frameworks will likely deepen their understanding and application of justice-oriented design.

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