Article

Design and Engineering: A Classification and Commentary

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Abstract: There are myriad understandings of design that have evolved over time and vary by the industries and disciplines that practice it. In the engineering context, design is often described as a process or problem-solving ability. Through interviews with 12 experienced engineers, it was found that there are diverse understandings of the relationship between design and engineering. This qualitative study presented a classification of their perspectives through three emergent categories: the relationship between design and engineering, the proportion of design tasks within a job, and the level or stage of development where design occurs. A synthesis of the data revealed that engineers demonstrate an ownership of design within engineering and there are diverse understandings of how design occurs within engineering. The implications of these findings were discussed and recommendations were offered for engineering educators, researchers, and industry. Engineering educators can help prepare designers as catalysts to produce a more inclusive, holistic, and sustainably minded profession.

Keywords: design; engineering; transdisciplinary; sustainable; engineering education

1. Introduction

Design is not a static concept. Rather, it evolves over time, encompassing diverse ideas due to its permeable, unstructured nature [1]. While once the designer was considered to be an artist, the inclusion of technical domains such as math and science shifted the responsibility of the designer to enter into the industrial process to determine how and what to produce [2]. Today, design is present in many industries, including: graphic design, fashion design, interior design, furniture design, architecture, information technology, education, engineering, medicine, and business [3]. The ever-evolving role of the designer and the dynamic nature of design can impede the identification of a collective understanding of design [1].

Studying perceptions of design, Smith and Whitfield found major differences between how design is perceived by designers and the public [3]. Designers identify with the professional designation such as architecture, whereas the public identify artistry as the dominant category of designers, such as fashion design. According to Whiting, design is neither art nor science, but rather the intersection between them [4]. Smith and Whitfield identified that little is understood about design in the public forum, academic institutions, or within the design profession itself [3]. Given the broad application of design, it is reasonable that there are diverse understandings of design.

> Cross summarized the literature on design from the 1960s, 1970s, and 1980s, concluding that designers must be able to 'resolve ill-defined problems, adopt solution-focusing strategies, employ abductive/productive/appositional thinking, and use non-verbal, graphic/spatial modelling media'.
>
> [5] (p. 20)

> *Design, then, encompasses problem-definition, ideation, and communication of ideas. Russell offered a broad definition of design, explaining that 'anything that is open to difference is open to design' where* difference *is interpreted as many material possibilities.*
>
> [6] (p. 37)

Galle asserted that design moves beyond the realm of thinking into a state of action [7] to encompass prototyping and production. In product design, *form, fit,* and *function* describe how the product meets the needs of the client [8].

> *There are numerous documented understandings of design, because as Lawson and Dorst explained, design 'is one of the most complicated human activities, and as such, design is a confusing term'.*
>
> [9] (p. 54)

> *In the engineering context, a ubiquitous definition of design provided by Dym et al., states that 'engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints'.*
>
> [10] (p. 104)

> *This understanding of engineering design as a process is reinforced by the engineering accreditation body in the United States that describes design as an iterative decision-making process 'of devising a system, component, or process to meet desired needs and specifications within constraints'.* [11] (p. 4)

> *Focusing on the person who is designing rather than the action, the Canadian engineering accreditation body describes design as an ability 'to design solutions for complex, open-ended engineering problems'.*
>
> [12] (p. 7)

Thus, there are different understandings of design, even within a single field.

Given the diversity of definitions for design, an exploration of the literature revealed existing design classifications. From publicly available interviews, Gulari analyzed the language designers use and documented metaphors to describe three aspects of design: designer, design process, and design knowledge [13]. First, the designer is a spokesperson, hero, or catalyst and climbs the ladder of expertise. Next, the design process is described as a black box or a journey. Finally, design knowledge is classified into repertoire and repository. In the realm of architecture and industrial design, Lawson and Dorst proposed a classification of design considering the nature of design activities (formulating, representing, moving, evaluating, and managing), layers of design expertise (seven categories from naïve to visionary), and levels of design activities (project, process, practice, and profession) [9].

In the engineering context, Lloyd and Scott asked five electrical engineers to verbalize their thoughts while designing and classified their responses into three phases of the design process [14]. Similarly, Gero and McNeill classified the micro-strategies (or steps in the design process) that were used by four designers who were speaking aloud while designing, and they determined the percentage of time spent in each design stage [15]. Kim and Lee documented the intersection between product design and engineering design and proposed four types of collaborative design processes [16]. They also found that engineering designers participated at the more detailed levels of design rather than at higher more conceptual levels [16]. Recognizing that engineering design extends beyond the design process, there is an opportunity to explore and classify how engineering and design are related.

In an exploratory study investigating qualities of design engineers, it became apparent that engineers hold different views about how design is practiced within engineering. This paper documented the classification of design and engineering that resulted from the

qualitative interviews, critically evaluated the implications of the findings, and offered recommendations for engineering educators, researchers, and the engineering industry.

2. Materials and Methods

2.1. Participant Data

Interviews were conducted with 12 engineers who met three criteria: (1) at least ten years of experience in an engineering industry, (2) design experience at some point in their career, and (3) management experience. Ten years of experience ensured the participants worked on a number of projects with different teams. Design experience was necessary to be able to discuss the relationship between design and engineering. Management experience qualified the participants to assess the skills and competencies of others. Participant data are shown in Table 1.

Table 1. Participant demographic and data.

ID	Highest Level of Education	Years of Experience	Gender	Discipline	Industry	Location
A	Bachelors	10–19	M	Electrical	Renewable power	Atlantic Canada
B	Bachelors	10–19	M	Mechanical	Utilities	Atlantic Canada
C	Bachelors	10–19	M	Software	Aerospace	Eastern US
D	Masters	10–19	F	Industrial	Mass-production	Southern US
E	Bachelors	20–29	M	Systems	Aerospace	Eastern US
F	Bachelors	20–29	M	Civil	Utilities	Atlantic Canada
G	Bachelors	20–29	F	Civil	Utilities	Atlantic Canada
H	PhD	20–29	F	Mechatronics	Marine robotics	Atlantic Canada
I	PhD	20–29	M	Systems	Aerospace	Western US
J	PhD	20–29	M	Mechanical	Acoustics	Western Canada
K	Bachelors	30–39	M	Electrical	Aerospace	France
L	Bachelors	40–49	M	Mechanical	Petrochemical	Midwest US

Stratified purposive sampling methods were used to ensure there was a diverse sample [17], considering the industry, geography, gender, engineering disciplines, education levels, and years of experience of the participants. Balancing the need for overall diversity resulted in a large representation of the aerospace industry (33%) and participants with 20–29 years of experience (50%). The sample included three women (25%) and four participants with graduate degrees (33%). Data about race were not collected for this study.

Five of the participants identified as designers, using the terms *design engineer*, *designer*, or *DE*. The seven participants who did not identify as designers at the time of the interview either had previous experience with design or performed design as a subset of their duties (not their main identity).

A qualitative approach was employed to generate a wealth of data. The findings are not intended to be representative of the greater engineering population [18]. Instead, the findings offer a possible classification of the relationship between engineering and design for these 12 participants. There is an established precedent in design research to perform qualitative interviews with experts [14,16,19–22]. Because the sample is not intended to be representative, a small number of participants is common [17]. Lloyd and Scott interviewed five experts [14]. Björkland interviewed seven experts and seven novices [19]. Crilly interviewed 13 experts [20]. Lee et al., interviewed 19 experts [22]. McAlpine et al., interviewed 27 experts [21]. Kim and Lee interviewed 34 experts [16]. Given the precedence set in similar studies and the richness of qualitative data, a sample of 12 is reasonable.

2.2. Data Collection and Analysis

Because of the vast geographic diversity, participants were given the choice of conducting the interview over the phone, through video conferencing software, or in person.

The duration of each interview was between 30 and 90 min, and field notes were recorded during the interview. Using an unstructured protocol, participants were asked to:

> *Describe someone you worked with who was a great designer, perhaps your mentor or someone who has worked for you, who always seemed to know the answer to a difficult problem. When you looked at their solution, you would think, 'that is so simple, why didn't I think of that?' Do you have someone that fits that description?*

Based on the participants' answers, follow-up questions were asked. Some participants were prompted to describe the relationship between designers and engineers using Venn-diagram terms if their initial responses went in this direction. The information was mined from the data for the remaining participants. Given the exploratory nature of the study, unstructured interviews were used to allow the conversation to be directed by the participant, prompted when necessary by the interviewer to ensure the essential topics were discussed.

Following *ex post facto* protocol, participants were provided a copy of the field notes to ensure accuracy of content and confirmability [23]. Following a generic qualitative inquiry framework [17], the edited notes were collected, and individual cases were constructed without categorization into data points using inductive analysis. A cross-case comparison was performed, and three categories of classification emerged. The data were reviewed again to classify each participant's data within the categories. This was an exploratory inductive study wherein the classification emerged from the data and was not the original intent of the interviews.

3. Results

From the interview data, the relationship between design and engineering could be classified in three ways: *relationship, level,* and *proportion. The relationship* category documents the four ways participants believe design and engineering are related, using Venn-diagram modelling. The *level* category documents where design occurs within an engineering project, whether initially at the system level or later in the detailed level of a project. The *proportion* category describes the amount of design tasks within an engineer's position.

3.1. Relationship between Design and Engineering

The *relationship* category explores the intersection between design and engineering and classifies the interaction from a high-level/program management perspective, considering multiple people and departments. There were four ways participants described the *relationship* between engineering and design: (1) as separate activities, (2) engineering as a subset of design, (3) design as a subset of engineering, or (4) with partial overlap, as shown in Figure 1. The fifth potential permeation of the Venn-diagram is that engineering and design completely overlap, but no participants held this view.

	Separate activities	Engineering subset of design	Design subset of engineering	Partial Overlap
Venn diagram of relationship				
Number of participants	3 (25%)	1 (8%)	7 (58%)	1 (8%)

Figure 1. The relationship between engineering and design.

Three participants considered engineering and design as separate activities, as shown on the top row. Participant C explained that '*a designer comes up with the overall system design and hands it off to engineers*'. This implies two separate positions, where design and engineering occur at separate times. Participant H agreed that the two activities are separate, but reversed the order, explaining '*engineers parse out sections to designers.*' Participant E's response aligned with this second view that engineers provide individual portions to the designers. (Note: The opposing views of whether design occurs at the system or detailed level inspired the creation of the *level* category.)

One participant viewed engineering as a subset of design, recognizing that design occurs in many fields. According to participant J, '*design is the ability to come up with a solution to a problem or an improvement on an existing solution, whereas engineering is a specific part of a design*'. This view assumes that all of engineering falls into an aspect of design, adhering to a transdisciplinary view of design.

The majority of participants (58%) held the opposite view, i.e., that design is a subset of engineering. According to participant G, '*design is one piece of the whole engineering puzzle. It is a critical portion, but not a large portion*'. The responses of participants A, B, D, F, I, and K aligned with this view. (Note: This identifies design as a portion of a job rather than the entire role of an engineer, which inspired the creation of the *proportion* category.)

Lastly, one participant distinguished between the two activities but saw partial overlap. Participant L described that '*there is one lead engineer/designer who would be creative, break down the problem, and supervise the engineers*'. While design could be an aspect of one engineer's job, it is not an aspect of another engineer's job. Thus, design is a part of engineering. This could suggest that participant L aligns with the third category; however, the use of the term *designer* implies that the person portioning off the tasks might not be an engineer. Thus, there is an aspect of design that is not engineering.

3.2. Level of Development

The second category documents the *level* of development where design occurs. First, design could be at the system level (high level), which occurs earlier in the design process in a more conceptual phase. Second, design could be at the detailed level, occurring later in the design process. Finally, design occurs at both the system and detailed levels. Figure 2 shows the number of participants who described design at each level.
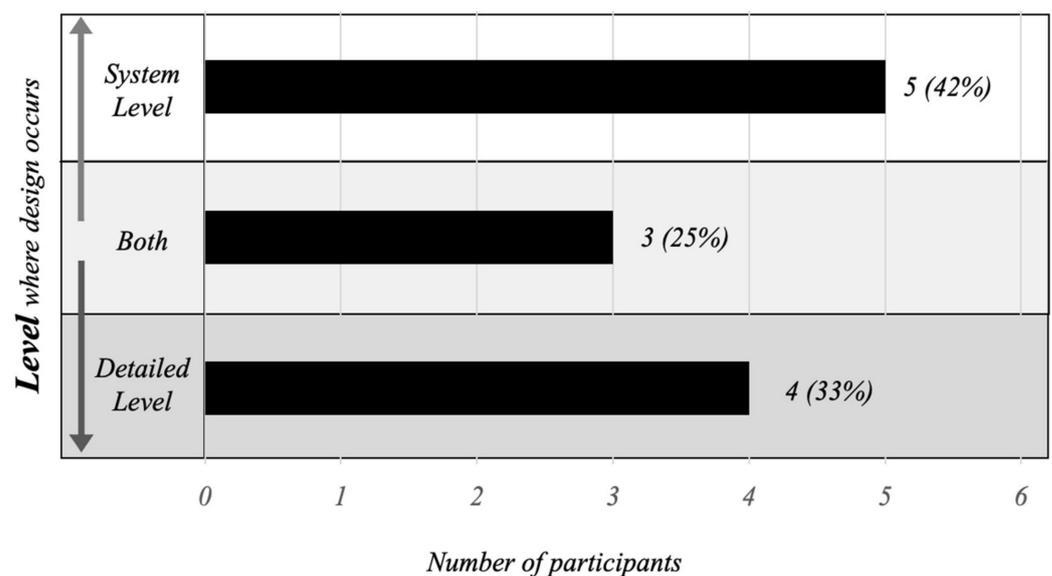

Figure 2. Level of development where design occurs.

Four participants described design occurring at the system level during the conceptual phase. Recall that participant L described the design engineer as the one to *'break down the problem, and supervise the engineers'* Participant C explained that *'a designer comes up with the overall system design and hands it off to engineers'*. The responses of participants D and F align with this view. Design would then occur earlier in the design process at the system level or high level, but not at the detailed level.

Five participants described design at primarily the detailed level, later in the design process. Recall that participant H stated that *'engineers parse out sections to designers,'* implying design occurs at a more detailed level. Participant E explained that *'an engineer looks at the whole picture, assesses, comes up with the design that meets the intent. The designer is focused on software, a part, runs a tool, but relies on the input they've been given'*. Additionally for participants B, G, and K, design occurs at the detailed level. Recalling the study by Kim and Lee, designers spent more time at the detailed level than the system level [16].

The responses from the remaining three participants (A, I, and J) indicated that design occurs at both the system and detailed level of development. Participant A described that *'design engineers see problems that have no solution. They go from broad to narrow in scope.'* This implies that design occurs at both the system (broad) and detailed (narrow) levels.

3.3. Proportion of Design in a Job

The third category is the *proportion* of design in a job. While the *relationship* category considers multiple people and teams, the *proportion* category focuses on how design and engineering interact in the job function of a single person who engages in design.

The *proportion* of design in a job can be: (1) design comprises the entire job for that person, (2) design is only a portion of the responsibilities that an engineer has, or (3) the data are not clear. These correspond with entire, partial, or unclear designations, represented as gears in Figure 3.
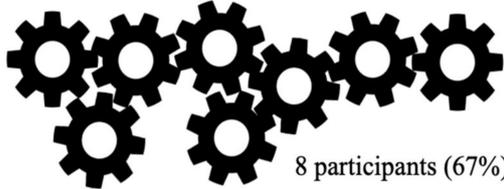
Entire job	Portion of job	Not discussed
8 participants (67%)	3 participants (25%)	1 participant (8%)

Figure 3. Proportion of design in a job.

Eight participants described design as the entire job. Participant G explained that *'engineers start as designers doing detailed work, and some move on to project management'*, supporting that design makes up most of the responsibilities for some engineers. This does not mean that design is the **only** function for **all** engineers, which would negate the *relationship* findings (and foundational literature). Instead, it implies that for people who engage in design, their job is primarily focused on design activities. The responses of participants A, C, E, F, H, I, and L align with the view that design is an inherent part of an engineer's entire job.

Three participants (B, D, K) stated that design is only one part of an engineer's responsibilities. As explained by participant B, *'design is one side of an engineer, project management is the other side'*. For this view, then, engineers balance design along with project management and other engineering activities. Note: this does not imply an equal weighting between project management and design, or suggest a particular percentage.

Participant J did not provide enough information to extract the proportion of design in a job, whether the participant believed design is a portion of the tasks or the entire job.

Because this was a theme that emerged during data analysis, it was not directly addressed during the interview and was categorized as 'not discussed'.

3.4. Synthesis of Three Categories

Patterns and additional information emerged through synthesizing the data. Figure 4 integrates the three categories, with each gear symbolizing a single participant.
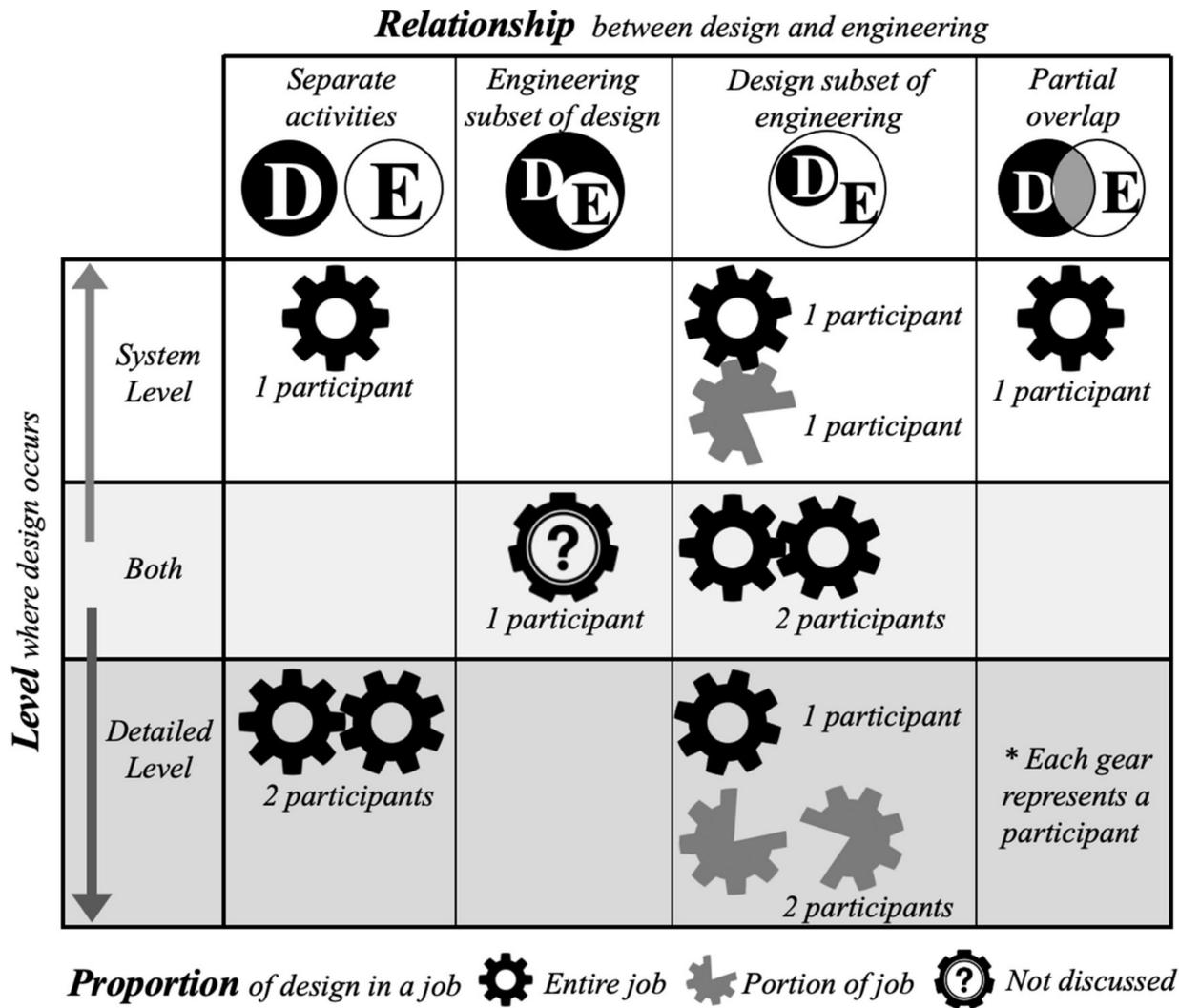

Figure 4. Classification of design, synthesizing relationship, proportion, and level categories.

The *relationship* between design and engineering is shown in the columns, and the *level* where design occurs is shown in the rows. The type of symbol corresponds to the *proportion* of design within a job (as in Figure 3). A full black gear signifies that design comprises the entire job. A partial grey gear signifies that design is a portion of the tasks of an engineer. A question mark signifies that not enough information was provided.

From the figure, when design is a subset of engineering (third column), the *proportion* of design in a job varies either as a portion or the entire position (partial and full gears). Although there are engineers whose job integrates design fully, there are also engineers who employ design as a portion of their job. However, when design and engineering are separate activities (first column), design is fully integrated into the position (only full gears). These are logical combinations of the categories, providing a level of validation across categories. It would be illogical for design and engineering to be separate activities and design to be a portion of an engineer's job.

The most populated cell has 25% of participants who believe that design occurs at the detailed level (bottom row) and is a subset of engineering (third column). Though responses varied on whether design is a portion of the full job for an engineer, these three participants shared the belief that design occurs at the detailed level and is performed by engineers. Note: This does not imply an equal weighting between project management and design, nor suggest a particular percentage.

An additional layer of information is whether the participants identified as design engineers at the time of the interviews. Table 2 combines this information on design identity with the categorical data.

Table 2. Design identity and synthesis of categories.

Relationship between Design and Engineering	Proportion of Design in Job	Level Where Design Occurs	Identify as Designer
Separate activities	Job	System	No
	Job	Detailed	No
	Job	Detailed	No
Engineering subset of design	Unknown	Both	Yes
Design subset of engineering	Task	System	No
	Job	System	Yes
	Job	Both	Yes
	Job	Both	Yes
	Task	Detailed	Yes
	Task	Detailed	No
	Job	Detailed	No
Partial overlap	Job	System	No

While all participants had design experience, only 5 of the 12 participants identified as engaging in design activities in their current position. These self-described design engineers believed that either design was a subset of engineering or engineering a subset of design (*relationship* category), but there was no correlation to the *proportion* or *level* categories. Three of these design engineers believed that the *proportion* of design is the full job, and because they believe that design is a subset of engineering, then it follows that there are engineers that they work with who are not design engineers. One design engineer believed that design is a portion of their job, and correspondingly, they also believed that design is a subset of engineering. It is appropriate that the participant who believed engineering is a subset of design identified as a designer, as they are an engineer and thus a designer.

The remaining seven participants did not identify as designers. Three participants saw design and engineering as separate activities, and thus as engineers, they did not identify as designers. Three participants considered design as a subset of engineering, and as participant B described that '*design is one side of an engineer, project management is the other side.*' Though all of the participants had management experience, these three engineers considered themselves to be primarily in management, as well as the participant who described a balance between engineering and design.

4. Discussion

Reflecting upon the data, we offer the following three points for discussion: (1) ownership of design as an engineering activity, (2) diversity of beliefs, and (3) designers as change agents.

4.1. Ownership of Design as an Engineering Activity

More than half of the participants described design as a subset of engineering. This connotes an interesting possessiveness of design within the field of engineering, suggesting an ownership or exclusiveness of the activity of designing. It is possible that participants were speaking about engineering design as opposed to design as a whole throughout the

discussion. However, all participants were provided with the field notes to make any corrections in their statements. A follow-on study could investigate the perception of engineers regarding the broader field of design and whether designers in non-engineering fields are similarly possessive of design.

Though not generalizable, these results suggest some engineers have a myopic focus on the field of engineering, ignoring other fields that utilize design. Admittedly, the ability to zero-in on pertinent information and disregard peripheral data is an asset for problem-solving. However, this fails to acknowledge the transdisciplinary nature of design. Whereas the term 'multidisciplinary' recognizes distinct boundaries between disciplines and the term 'interdisciplinary' acknowledges common elements through blurred discipline boundaries, the term 'transdisciplinary' eradicates the boundaries between disciplines to create holistic commonality [24]. Design ascends above a single industry and is woven throughout different fields in a transdisciplinary fashion. Knight explains,

> *Design is increasingly identified as an activity that is integral to work in diverse disciplines, from management to engineering to the humanities to architecture to media arts and sciences and more. Moreover, within a discipline, design is increasingly recognized as entailing some synthesis of best practices and pedagogies from outside fields.*
>
> [25] (p. 20)

> *Rather than being focused within its own field, design looks to other disciplines to incorporate praxes to continually transform. According to Valtonen, 'to design is to seek change,' to be in constant evolution, moving beyond any one industry.*
>
> [26] (p. 506)

The participant who described engineering as a subset of design likely upholds the transdisciplinary nature of design.

> *A concept called 'Big-D Design' promotes the expansiveness of the design discipline, including architectural, product, software, systems, and any technical-based design. 'It is design through conception, development, prototyping, manufacturing, operation, and maintenance',*
>
> [27] (p. 3)

with the recent addition of recycling, reuse, and overall sustainability [25]. Inclusive of the liberal arts, humanities, and social sciences, Big-D Design recognizes both the art and science of design. If engineers embrace this expansive view of design, there will be a wealth of industries to draw from, with different approaches to problem solving that could be applied in new settings.

In order to innovate, Norman explains that designers should be generalists, knowledgeable of diverse industries, to seek out specialists to develop their designs [28]. This is reminiscent of participant C's statement for the designer to hand off the design to engineers. The three participants who described design and engineering as separate activities may share a more transdisciplinary understanding of design.

Adding technical depth to the breadth of generalists, designers display both depth and breadth of knowledge, embodying the T-shape popularized by David Guest [29]. Engineering education critics are challenging university programs to produce engineers who are technically competent in one field (the vertical bar) and understand broadly across multiple fields (the horizontal bar) [30]. A similar model is the pi-shaped model, which encourages systems engineers to display a depth of systems knowledge and one technical proficiency (comprising the two vertical columns) in addition to breadth of general knowledge (comprising the horizontal column) [31]. The I-shaped model highlights the interdisciplinary connectedness of the humanities (bottom bar) in the local and global context (top bar), integrated by technical and innovative engineering (vertical bar) [32]. Regardless of the shape, these models advocate for the need for engineers to extend beyond an area of specialization. Recognizing that design is an engineering activity (supported by

accreditation bodies, research, and nine of the participants) [10–12], engineers can realize the necessary breadth through embracing the transdisciplinary nature of design.

4.2. Diversity of Beliefs

The distribution of responses across the synthesized classification shown in Figure 4 highlights the diverse understandings of the relationship between design and engineering. Seven of the 12 cells comparing the *relationship* and *level* categories are populated. Integrating the *proportion* category provides nine distinct understandings of the relationship between design and engineering. With so many different understandings, it is not surprising that there are directly conflicting views about how design and engineering are related. Considering the various industries that practice design and engineering, each with their own procedures and standards, design would be implemented differently in each situation. In some industries, design might be more apparent at the system level, whereas for other industries, it might be more apparent at the detailed level. The variation could occur from company to company within the same industry, warranting further study.

An analysis of case study excerpts presented in Jesiek yields a similar diversity of beliefs [33]. One participant experienced design as the entire job whereas the second participant described design as a portion of the job. The third participant separated design and engineering into two separate activities with design occurring at the system level. Admittedly, there are limitations mining data from a manuscript for a different purpose than the stated research objective, yet there is the diversity in the relationship between design and engineering in their responses parallels the findings in our research. This confirmation validates the diverse findings of this study and highlights the lack of consensus on the relationship between design and engineering.

The diversity of definitions for design (cited in Section 1) emphasize the ill-defined understanding of design in the workforce. The diversity of beliefs found in our study is troubling for university programs. If there is little congruence between practicing engineers on how design occurs in industry, how can universities adequately prepare students to enter the workforce?

In interviews with students about the necessary skills for engineering, students reported requiring a particular engineering mindset, citing examples of math skills, teamwork, hard work, and creativity, but design was not explicitly reported [34]. Given the book-end cornerstone and capstone design course model that exists in many universities, this result is not surprising. However, universities have the opportunity to shape the engineering culture through educating students who will enter and eventually influence the workforce [34]. While universities try to be responsive to the needs of industry by developing new types of engineering profiles, there is a need to shift focus from the individual to recognize the greater ecology within the field of engineering to shape industry [35]. Once the practices and needs of industry are better understood, universities can tailor programs to produce graduates to help shape the ecologies.

4.3. Designers as Change Agents

The multitude of definitions for design can result in a misappropriation of the term, undermining the role of the designer [4]. If design is truly part of every engineer's job, then that skill should be cultivated in all engineers. Rather, if design occurs only during heightened problem-solving or innovative moments, design engineers should be trained as specialists to support as consultants. Similarly, specialized attention can be devoted at the appropriate stage of development, whether design occurs early in the problem-solving process (at high levels), later in the detailed elements, or throughout.

Ehrenfeld explained that the design process relies on both theory and intention to solve a problem [36]. Designing without intention can result in a lack of clarity and wasted time, effort, and materials. Whether the intention is towards economic interests, strict schedules, innovation, or a global connectedness, it is primarily shaped by the practices in the workplace. These practices are established social phenomena that are repeated and

relatively stable over time [35]. Conflating a nation of workplaces, the American identity is characterized by the mass consumption of low-cost goods [37]. However, the intention of a workplace can change, not by individual action or specific change, but rather through an ecology of practices [35]. Spearheaded by the intentionality set in design practices, it is possible to change an existing culture.

> *Price et al., defined design as 'a collection of methods, processes, and skills to negotiate problems that concern industries, networks of organizations, and society as a whole'.*
> [38] (p. 305)

Practicing design in an intentional way has the potential to benefit all of society, in the short-term through informed product design, and in the long-term through redefining workplace practices.

> *Economic prosperity can result from an intentional design practice, as 'designs are recognized as one of the most significant means for a society to improve its economic and social well-being'.*
> [25] (p. 36)

Designers can build upon existing structures to create new opportunities for prosperity, working within the existing value system while incorporating more holistic intentions.

In order to solve complex, dynamic problems, designers need to be able to identify hypothetical patterns of relationships [39]. A fragmented understanding of a given situation results in an inability to adequately resolve difficult challenges. According to Buch,

> *The problems that engineers will face in the future are often unique, complex, heterogeneous, ill-defined, and even wicked. Past solutions will no longer suffice. In order to solve these problems, engineering education must develop a new 'breed' of engineers that are innovative, cross-disciplinary, collaborative, and holistic.*
> [40] (p. 141)

The complex problems of the current climate cannot be solved by repeating past practices or with an incomplete understanding. In order to create change, current design practices must be examined, evaluated, and transformed.

This is a time of rapid change. The culture is awakening to the marginalization of people based on identity, gender, ethnicity, race, and sexuality. In engineering, though efforts have been made towards a more inclusive environment, change is proceeding at a slower pace. In the United States and Canada, engineers have traditionally been masculine, white, heterosexual, middle-class men [41]. Though starting salaries for women entering the workforce were comparable to their male counterparts in the early twenty-first century, women who are now in their thirties have fewer opportunities for promotion and experience greater salary disparity, matching the unfortunate reality for women entering the workforce during the second half of the twentieth century [42]. Gratefully, the culture is slowly changing. There is a call to create new inclusive spaces for women and individuals in the LGBTQA community to practice new ways of interacting, particularly in university engineering programs [43]. Indigenous perspectives are being documented to broaden the narrative and amplify non-dominant voices [44,45]. Design pedagogy is expanding to promote a global consciousness with a focus on social justice [46]. Humanitarian and socially responsible engineering have emerged to incorporate ethical decision making promoting the welfare of all humans [47]. Employing an empathetic mindset allows designers to weave together divergent perspectives to satisfy client needs [48]. Lastly, eco-social design approaches address complex interconnected problems by looking for patterns in an attempt to provide more sustainable solutions [49].

This openness to inclusivity and designing for the well-being of all people and beings on the planet can be expressed through Ehrenfeld's concept of flourishing [36]. Through a vision of all things flourishing together, flourishing is the realization of the potential for all biological (and existential) organisms. When combined, there is a great multitude of effort towards a holistic vision of all people and things flourishing together. Each call for

change or new design praxis works towards the greater vision. On a daily basis, engineers choose whether to prioritize sustainability over profits [50]. They have the ability to affect the overall company practice by employing those small changes each day.

Unfortunately, effecting change is often met with resistance. Buch documented one team's attempt to incorporate holistic engineering practices to address major causes of climate problems while employed in a consulting company [40]. In order to meet tight profit margins, strict timesheet documentation protocols left little room for reflective practices or innovative discussions, which resulted in descoping to a less ambitious goal of monitoring CO_2 emissions [40]. Attempts to incorporate new practices into an existing system requires more patience and a slower timeline.

> *Interviews with 25 practicing engineers on the role of empathy and care in engineering revealed that 'within engineering organizations, if empathy-related phenomena are not core to the organizational culture, they will likely not gain widespread traction at the individual level'.*

[48] (p. 235)

The challenge then becomes how to affect change at the organizational core.

Employing ecologies of practices [51], individuals can work together to make a larger change to the corporate identity. Changing the culture is not easy, but ultimately it can provide meaning and depth to an engineer's identity. In a study of six engineering firms, it was found that engineers derive satisfaction when their work has meaning [52], whether that is helping the environment, building a hospital, or performing a task that the person finds meaningful. When an engineer sees the value in their task, these leaders can become catalysts for change, even in a large corporation. A study documenting early career narratives found that empowering engineers early in their career can create change agents within a company [33]. By employing intentional design practices, a collective of change agents can help to hasten the tedious progress towards an inclusive design culture, enacting flourishing for all beings. Educators are in prime positions to shape the engineering students to become change agents.

4.4. Recommendations

Engineers are essentially problem solvers. It would not be enough to point out existing problems without suggesting a path forward. The three discussion points pose problems that can be addressed in multiple engineering forums: education, research, and companies. First, an ownership of design within engineering suggests a myopic focus that can be countered by adopting a more transdisciplinary mindset. Second, engineers' possessiveness of design is reminiscent of the historic and contemporary exclusivity of the engineering profession that is explored in the third discussion point. This exclusivity can be countered through viewing designers as agents of change, able to collectively change the ecology of a particular workplace towards an inclusive environment producing holistic, global, and sustainable designs. Lastly, diverse understandings of how design is incorporated within engineering can result in a lack of a design identity within companies. A lack of agreement can result in a vacuum for fragmented understanding and meandering processes. If there is more definition on the relationship between design and engineering with industries and companies, universities can better equip graduates with the necessary knowledge and skills.

Engineering educators and universities can prepare students following the T-model (or a similar model) to encourage transdisciplinary breadth and depth in a technical area. Design projects in technical courses could be practical applications to gain transdisciplinary depth and technical depth. Implementing projects in a technical course would anchor students' understanding of design as an engineering activity. Design courses could incorporate social justice values, sustainability practices, and diversity training to create future agents of change.

Engineering researchers can undertake projects to further define the relationship between design and engineering. What is the perception of engineers regarding the broader

field of design? Are designers in other (non-engineering) fields as possessive of design? Are there causal links between particular industries and their understanding of design? Engineering researchers have responded to the call to document non-dominant cultures in engineering education and the profession, but the task is not complete. There is an ongoing need to document and innovate how sustainability, global engineering, and social justice are being considered throughout the profession.

In industry, company culture should be explored to determine whether formal and informal gathering spaces are inclusive for people in the non-dominant company culture (namely people of color, women, and people in the LGBTQA community). How open is the culture to change agents and new practices? Company core values can be reviewed to incorporate global, holistic, and sustainable values, followed by a revision of policies and procedures to ensure a reorientation towards the values can be successfully implemented. Practicing engineers can reflect on whether they identify as designers and how design is implemented in their project. They can become agents of change and partner with others in the company to effect transformation.

4.5. Limitations

It is important to note that this study does not seek to promote one combination of categories as the correct definition. Rather, this tool documented the multitude of ways the 12 participants described design and engineering, laying the groundwork for future studies. In a qualitative study, there is the potential for bias during the interview in the analysis of responses or the synthesis of data, which is described as researcher bias [53]. It is therefore necessary to document the design beliefs of the author who performed the interviews and data analysis. She believes there is a partial overlap between design and engineering (the fourth column), wherein there are some transdisciplinary design activities that do not include engineering and some engineering activities that do not incorporate design. Additionally, she believes that design occurs at both the detailed and system level (second row) and design is a portion of a job (partial gear). Though she is a design instructor, she does not currently identify as a practicing designer. According to Figure 4, there are no other responses in the corresponding cell, so the interviewer or analyst bias is minimized.

5. Conclusions

The aim of this study was to document a classification of design in the engineering context that resulted from interviews with 12 experienced engineers, and discuss the implications of the findings. Three categories were developed from the interviews: the relationship between design and engineering, the proportion of design in a job, and the level or stage of development in which most design occurs. The relationship category produced four options: design and engineering as separate activities, partial overlap between the two, engineering as a subset of design, and design as a subset of engineering. The level of tasks category suggested design can occur only at a system level, only at a detailed level, or at both levels. The proportion of design in a job produced two categories, where design is the entire job or design tasks are only a portion of the overall number of tasks.

The classification indicated that there are a multitude of understandings about how design is implemented in engineering, and also that engineers have a perplexing level of ownership of design as an engineering activity. This lack of design identity and exclusivity reflect an industry that is resistant to change. However, intentional discussions on how design is implemented in engineering can create designers as agents of change to create a more inclusive, holistic, and sustainably minded engineering environments.

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