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Citation: Das, Madhurima, Roeder, Gillian, Ostrowski, Anastasia K, Yang, Maria C and Verma, Aditi. 2022. "What Do We Mean When We Write About Ethics, Equity, and Justice in Engineering Design?." Volume 6: 34th International Conference on Design Theory and Methodology (DTM).

As Published: 10.1115/detc2022-87373

Publisher: American Society of Mechanical Engineers

Persistent URL: <https://hdl.handle.net/1721.1/154866>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

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WHAT DO WE MEAN WHEN WE WRITE ABOUT ETHICS, EQUITY, AND JUSTICE IN ENGINEERING DESIGN?

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ABSTRACT

Engineering design often requires engaging with users, clients, and stakeholders of products and systems. It is therefore important for designers to reflect on the societal and environmental implications of their design work so that they can design equitably, ethically, and justly. We conduct a review of three leading scholarly engineering design venues to investigate how, when, and why these terms – “ethics,” “equity,” and “justice,” and variations — appear in the engineering design literature and what scholars mean when they use them. We find that these terms are minimally present within the field’s scholarship and posit that design researchers may be using other terms to refer to their work that is aligned with principles of ethics, equity, and justice. We find that the prevalence of these terms has increased over time and that the terms come up throughout various stages of the design process. There appear to be a variety of motivations for including these terms, notably, sustainability and education of the next generation of designers. Finally, we propose an expanded design justice framework that is specific to engineering design. We encourage designers in our field to adopt this framework to assist them in thinking through how their engineering design work can be used to advance justice.

Keywords: engineering design, design justice, literature review

1. INTRODUCTION

1.1 Background and Motivation

There are growing calls and an increasing sense of urgency surrounding the need for engineering design researchers and

practitioners to engage with the social implications of their work [1,2]. Anxiety around the Climate Crisis [3], controversies surrounding Big Tech [4,5], and public outcry for social justice, particularly after the Black Lives Matter led social movements in 2020, have highlighted that engineered systems can have lasting negative effects. These impacts range from algorithms trained with historical data suggesting that Black men should spend more time in prison than their white counterparts for the same crime [6] to products initially designed to help people quit smoking that are instead getting young people addicted to smoking early [7]. While efforts are being made by many to approach design problems through a more socially-oriented lens [1], we seek to understand the extent to which engineers are directly and meaningfully engaging with themes of ethics, equity, and justice (EEJ) in their work. For example, in engineering design, topics synergistic with design justice [8] might include “sustainability,” “resource-constrained design,” “human-centered design,” “participatory design,” and “co-design.” Though each of these approaches emphasize equitable design, each treats a specific form of inequity in design. For example, resource-constrained design explores approaches for designing in settings such as developing countries in the Global South. User-centered design methods prioritize uncovering needs and getting feedback from users in the design process rather than focusing on technology first. Human-centered design processes such as participatory design and co-design go beyond the informant based model of user-centered design, seek to make the design process more equitable and democratic, and emphasize users as main contributors in the design process [9]. Sasha Costanza-Chock and the Design Justice Network

have established the Design Justice framework to help designers think through how design can be used to promote justice, or conversely, perpetuate injustice [8,10]. This framework ties together concepts across various fields and even within a single field to holistically address different forms of inequity by urging designers and researchers to consider questions such as *who is designed for and with, how the sites of design work are impacted by that activity, whose values are encoded in designs and how, who benefits from design work and who has ownership of the design work* [8].

The broad terms “ethics,” “equity,” and “justice” are used across a variety of disciplines, alongside design practices such as participatory design and co-design, both within and beyond engineering to discuss topics related to design justice [11]. As a result, these three key terms are the focus of our engineering design literature review presented in this paper and definitions for each are provided below. In our ongoing work, we are similarly carrying out ethics, equity, and justice reviews of other disciplines including human computer interaction, human robot interaction, and nuclear engineering.

Ethics is composed of individual ethics, focusing on “values such as *integrity, honesty, competence, safety, and social and environmental responsibility*” in design processes and decisions, and social ethics investigating “social arrangements that are made for making the decisions about technology rather than on either the individual or the decision itself” while exploring the values listed in individual ethics [12].

Equity addresses fairness by aiming to “intentionally close societal gaps rather than unintentionally expand them” [1].

Justice focuses on “practices that strive to enhance human capabilities (goal) through an equitable distribution of opportunities and resources while reducing imposed risks and harms (means) among agentic citizens of a specific community” [13].

Put plainly, ethics is primarily focused on assessment of moral right and wrong, equity is concerned with delineating whether or not something is fair, and justice is focused on taking a position towards making the world fairer by attempting to change or eliminate the system that creates inequity (rather than attempting to be objective).

This paper investigates how ethics, equity, and justice are represented in the engineering design literature, how these representations have changed over time, how the presence of these terms varies throughout the design process, and why researchers are motivated to include them. We make two main contributions: (1) we present an assessment methodology and results of a comprehensive literature review of ethics, equity, and justice in engineering design; and (2) we describe a new framework for engineering design researchers and practitioners to ground their work in design justice.

1.2 Research Questions

RQ1: How are ethics, equity, and justice represented (or not) in the engineering design literature?

This question seeks to understand the context in which these keywords appear within the engineering design literature. In particular, which terms are used, and how? Are the terms used meaningfully, or do they seem to be added as an afterthought? Based on our audit of engineering pedagogy [14], we hypothesize that ethics will be much more present in engineering design literature than equity and justice as it has long been a required element in many engineering curricula and professional societies.

RQ2: Has the presence of ethics, equity, and justice in engineering design literature changed over time?

We hypothesize that the terms are more likely to be prevalent as well as directly related to the central themes of recent papers due to the increased awareness and discussion around topics related to diversity, equity, and inclusion within the public sphere.

RQ3: When in the design process and design research process are ethics/equity/justice considered?

This research question investigates which stages of design and design research are most attuned to ethics, equity, and justice considerations. For instance, are these terms being explored during early phases such as ideation? Or are they typically used to analyze failures or product end-of-life scenarios?

RQ4: What are the motivations for including ethics, equity, and justice in engineering design literature?

This question explores the context through which each of these terms are used in engineering design papers and how each paper’s motivation connects to ethics, equity, and justice. As with RQ1, we hypothesize that many of the papers in the field will use these terms lightly rather than integrating them as core parts of the paper’s motivation. We expect this to be the case because while many researchers may acknowledge that their work has ethics, equity, and justice implications, they may not have access to conceptual frameworks for treating these considerations in a holistic way.

2. METHODS

Our paper focused on the presence of three key terms, ethics, equity, and justice, within engineering design scholarship. We developed a systematic literature review methodology to study the prevalence of these terms in engineering design literature [15]. We refer to engineering design scholarship as engineering literature that has a design focus that we further define through the selection of venues for this literature review. We selected three leading engineering design research venues as the primary source of our data: the American Society of Mechanical Engineers (ASME) International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC-CIE), the ASME Journal of Mechanical Design, and the Research in Engineering Design journal. The

starting year for availability of papers online, total number of papers available from the starting year through 2020 and the number of papers found from our search are listed in Table 1. We searched for our three key terms along with several variations (ethical, unethical, equitable, inequitable, inequity, unjust, and injustice) in paper titles, keywords, and abstracts which yielded 25 total results for all time across all three venues¹. In order to find the papers where these concepts were a central focus, we limited our search to the paper titles, abstracts, and keywords rather than the full body of the text.

TABLE 1: THE STARTING YEAR FOR AVAILABILITY OF PAPERS ONLINE, NUMBER OF PAPERS AVAILABLE THROUGH 2020 AND NUMBER OF PAPERS FOUND FROM OUR SEARCH OF ALL THREE VENUES.

	ASME IDETC- CIE	ASME Journal of Mechanical Design	Research in Engineering Design
Earliest Year of Online Paper Availability	2006	1978	1989
Number of Papers Available Online (through 2020)	16,822	36,501	634
Number of Papers Found in EEJ Search	18	3	4

2.1 Inclusion and exclusion criteria

Following this initial phase, we began our inclusion/exclusion process, as shown in the flowchart in Figure 1. First, we only included full research papers. This means that workshops, short papers, panels, and editorials were excluded from the analysis. Subsequently, we assessed whether or not the terms ethics, equity, or justice were used in a societal focused context. Occasionally, papers had one of these terms in the text or keywords but it was used in a very different and unrelated context. For example, two papers that included the word “equity” did so not in a social context, but with reference to the “equitability of results” of an experiment or simulation or an “equitability preference” for an optimization problem [16,17]. Once these were removed, we had a total of 19 papers left.

¹Table of all papers from the search can be found at [10.6084/m9.figshare.19027319](https://figshare.com/figures-and-tables/10.6084/m9.figshare.19027319).

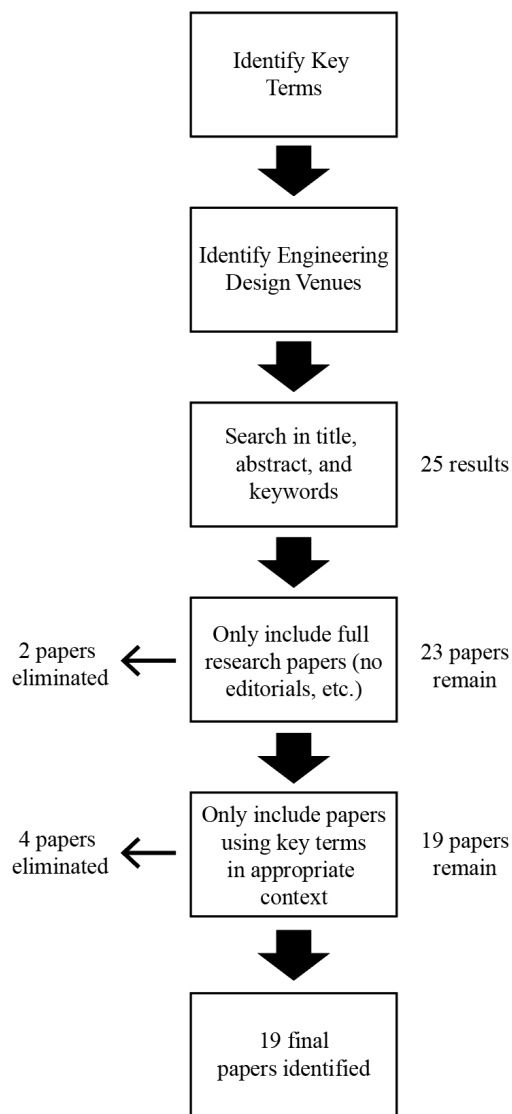


FIGURE 1: FLOWCHART SHOWING THE SELECTION PROCESS AND HOW MANY PAPERS WERE ELIMINATED AT EACH STAGE

2.2 Assessment of Meaningfulness

Several papers included the three keywords as an add-on rather than as a fundamental part of the paper. For instance, some papers mentioned “ethical commitments” or “ethical considerations” without including a discussion of what these commitments or considerations might be. We included these papers in the sample of papers reviewed as we believe it is important to shed light on the various ways in which the engineering design scholarly community uses these terms and the meanings it ascribes to them. Subsequently, to assess how

meaningful the inclusion of EEJ was in each paper, we used a two-tiered scale, as shown further in Figure 2.

The first layer of granularity was related to the extent of the explicit consideration of EEJ in the body of the paper compared to the most visible parts of the piece such as the title and abstract. If the terms were featured in the title, abstract, references, department or position of an author, or keywords of the piece without subsequent inclusion in the rest of the paper, we would not define the paper to have meaningfully included them. It is likely that papers that fall under this category are attempting to consider the societal implications of their work by contextualizing their thesis and contributions with a socially minded explanation, but fail to take the final leap of integrating these considerations throughout the paper. However, it is possible that papers considering EEJ topics meaningfully but implicitly are eliminated through this first stage of filtering.

The final determinant for how meaningful a paper's inclusion of ethics, equity, and justice is the clarity of intention. A paper could mention ethics, equity, or justice in a social context frequently throughout the paper but still not be considered meaningful if their inclusion is unsubstantiated or without reason. For example, one paper mentioned ethics four times outside the abstract, often in statements like the following: "Sustainability, ethics, health, and safety features were considered in relation to the design specifications, manufacturability, and design scalability" [18]. In this example, "ethics" was mentioned frequently in the paper as part of a broader list of considerations. However, there was no explanation of what ethics meant in the context of designing and fabricating the product in question, leaving the reader to create their own interpretation of what ethics meant in the paper. When a paper uses ethics, equity, or justice without an accompanying definition to understand the context in which the word is being used, or if the word seems to be used in an impromptu manner, its inclusion is not meaningful by our standards.

A meaningful inclusion of justice is exemplified by one paper, "Toward Implementing Quantifiable Social Justice Metrics in the Design Process." Justice is an extensive focus throughout the paper, with the term appearing 88 times in the body of the nine-page piece, thus meeting the first criterion. The second criterion is met after justice is clearly defined early in the work as "1) listening contextually, 2) identifying structural conditions, 3) acknowledging political agency and mobilizing power, 4) increasing opportunities and resources, 5) reducing imposed risks and harms, and 6) enhancing human capabilities," with each of these categories discussed in further detail [31]. The paper creates a concrete definition of what justice refers to and integrates justice into the context of their engineering goals. This explicit and intentional inclusion of justice classifies it as meaningful inclusion of the term.

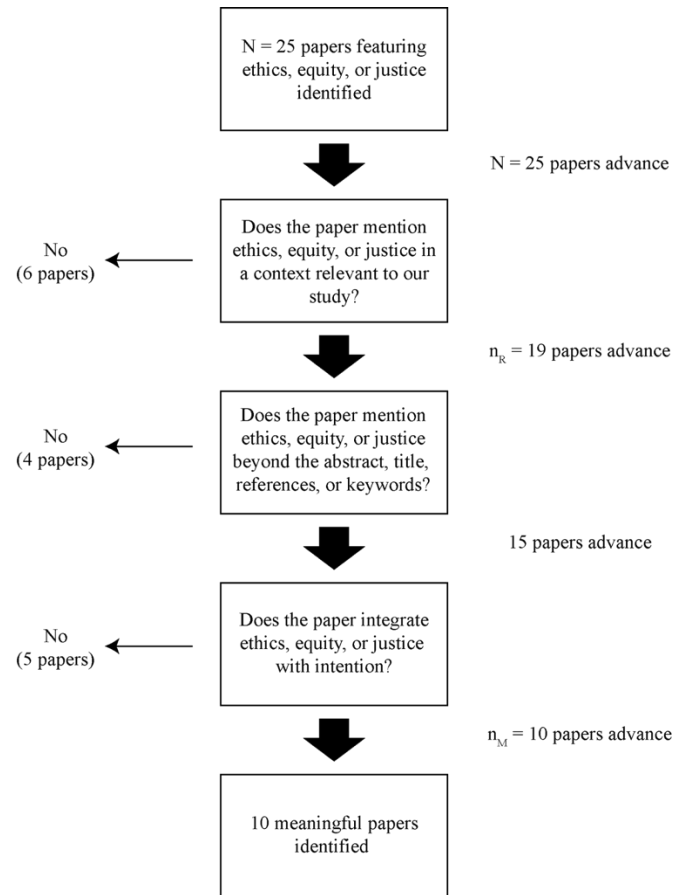


FIGURE 2: FLOWCHART OF HOW “MEANINGFULNESS” WAS ASSESSED FOR EACH PAPER

Two members of the research team independently rated the meaningfulness of the inclusion of the terms ethics, equity, or justice. All were rated as a yes/no binary. Percent agreement between the researchers for this “meaningfulness” assessment was 89% (17 of the 19 papers) and Cohen’s Kappa was 0.79. These values indicate substantial agreement for inter-rater reliability [19]. After this initial round of rating, the researchers discussed each paper and resolved discrepancies in order to decide the final ratings for each paper.

In addition to these ratings, the researchers made notes in an annotated bibliography on how each paper could better address design justice questions along with general notes about strengths and weaknesses of the paper. They then read through all of the notes and wrote research memos regarding common themes across the papers. We have included themes and commentary from these memos in our results.

To conduct analyses and draw conclusions on when, how, and why ethics, equity, and justice are featured in the engineering design literature, we needed to define common categories for these topics. We used a grounded-theory approach to identify design stages during the analysis [20]. To start with, we read through each paper and individually attempted to categorize the

stage of the design process in the context of which ethics, equity, or justice was presented in the paper. We reconvened and showed each other the list of terms we had developed without reference to which piece they applied to in order to not confound our inter-rater reliability. We devised a single list of common terms and definitions and then individually went through the papers again to evaluate which of the agreed upon stages of the design process applied to each paper. Next, we conducted our inter-rater reliability check and discussed disagreements in order to determine a final set of design stages. We repeated this process to determine the definitions for each context of the use of EEJ terms along with the motivations for the papers. The results from these stages are discussed in the Results section.

3. RESULTS AND DISCUSSION

The results are presented in the context of each research question, with one subsection per research question.

3.1 RQ1: Representation of EEJ Terms in the Literature

25 papers across all three venues for all years available online through 2020 included “ethics”, “equity,” or “justice” in the title, keywords, or abstract. This is from a total of 53,957 papers in these venues, representing less than 0.05% of the total content in these venues. Subsequent analyses were performed on the 19 papers that were relevant to the analysis.

To ensure clarity, we will use the following notation in describing subsets of papers:

- N=25, representing the total number of papers collected
- $n_R=19$, representing the number of papers we deemed relevant to our analysis
- $n_M=10$, representing the number of relevant papers we deemed to address the terms in a meaningful manner

Within the 19 relevant papers identified by this search for each EEJ term, around half did not actually include the topic in the paper. The breakdown of papers across the three keywords can be seen in Table 2. Some papers that included ethics as a keyword actually discussed equity in the paper instead. This indicates that there is confusion regarding these words and they are potentially being inadvertently used interchangeably.

Note that some papers discussed also multiple EEJ terms within a single paper. As such, the number of papers identified as including each EEJ topic in the paper (row 2 of Table 2) adds up to more than 10 (n_M).

TABLE 2: NUMBER OF PAPERS ($n_R = 19$) THAT INCLUDED ETHICS, EQUITY, OR JUSTICE IN THE TITLE, KEYWORDS OR ABSTRACT ALONG WITH THE NUMBER OF PAPERS THAT INCLUDED THE TOPIC WITHIN THE PAPER.

	Ethics	Equity	Justice
All search terms	Ethics, Ethical, Unethical	Equity, Equitable, Inequity, Inequitable	Justice, Unjust, Injustice
Included word in title, keywords, or abstract	12	5	2
Included the EEJ topic in the paper	6	7	1

We cataloged the context of the use of the terms ethics/equity/justice throughout the papers, and found several patterns. A summary of the context of the use of the terms along with the frequency of their use can be found in Table 3. One category of papers used vague language such as “ethical considerations” to provide a nod to ethics without meaningfully discussing what ethical considerations might be. Several papers were focused on training the next generation of engineers to consider ethics, equity, or justice more meaningfully. Another category of papers was focused on helping broaden access to technologies or ensure equitable distribution of resources. Very few papers focused on engineering ethics or ethics of experiments. Many papers had a strong focus on sustainability and used that term interchangeably with ethics. A final category focused on ethics in the corporate world.

TABLE 3: OUR DEFINITIONS FOR EACH CONTEXT OF THE USE OF THE TERMS ETHICS/EQUITY/JUSTICE ALONG WITH A REPRESENTATIVE EXAMPLE FOR EACH.

Context of E/E/J term use	Definition	Example	Number of Papers (nr) using each Context
Ethical considerations	Ethics, equity, and/or justice are used in passing or as a buzzword without a clearly defined meaning or intention.	Stating that it is unethical to make assumptions about the personality of a group member (i.e. [10]).	3
Teaching Ethics/ Equity/ Justice	Ethics, equity, and/or justice are included in a curriculum, teaching module, or program.	Teaching engineering with more ethical case studies than traditional approaches (i.e. [21]).	4
Sustainability	Ethics, equity, and/or justice are defined as a near synonym of sustainability, and they are used in the context of addressing environmental concerns, Climate Change, and/or resource usage.	Framing equity as one of “three main pillars” of sustainability (i.e. [22]).	3
Experimental Ethics	Ethics is discussed with respect to its role in experiments on human subjects.	Contextualizing the research methods used to activate select areas of the brain with an unethical way of doing so (i.e [23]).	1
Engineering Ethics	Ethics as it relates to rules and expectations of the practices of engineers	Assessing the role of designers, park owners, workers, and inspectors in an amusement park accident (i.e. [24]).	1
Corporate Ethics	Ethics is considered by a business or in a business context	A company considering the ethical implications of withholding news of engineering misconduct (i.e. [25]).	3
Equitable access/ distribution	Ethics, equity, and/or justice are considered with the main intention of providing goods, services, and/or opportunities to a group at large.	Attempting to combat energy inequity and looking at equity as a means of increasing efficacy of climate action (i.e. [26]).	4

3.1.1 One and Done

It was common for papers to reference ethics, equity, and justice in the title, abstract, and keywords of the papers without systematic (or any) inclusion in the body. Figure 3 shows the ratio of inclusion of the terms in the body to how often the term appeared in the rest of the piece for each paper. Out of 19 papers, over half had two or fewer mentions of ethics, equity, or justice outside of title, abstract, keywords, and references. Four papers did not discuss the terms outside of those sections of the paper at all. When taking the number of pages into account, the results remained consistent. Papers ranged from three to nineteen pages, and only five averaged one or more allusions to ethics, equity, and justice in the body per page. Such infrequent inclusion suggests a general lack of meaningful representation of ethics, equity, and justice in engineering literature. However, it is important to note that this rote keyword search does not take into account papers that mentioned any of the EEJ terms implicitly, or by using related

terms like “inclusivity” or “fairness.” A more nuanced search may reveal that the true number of papers that meaningfully engage with EEJ is more than the value we measured.

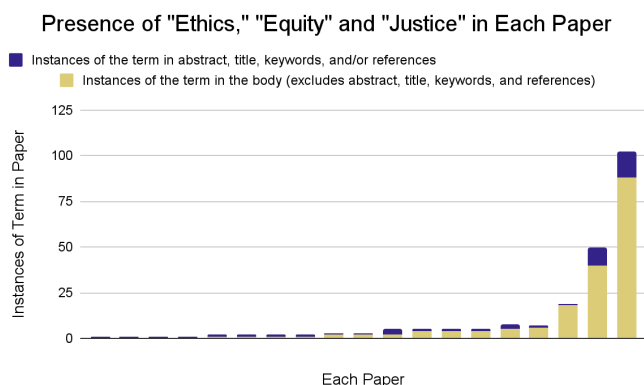


FIGURE 3: GRAPH COMPARING THE USAGE OF “ETHICS,” “EQUITY” AND “JUSTICE” IN THE BODY WITH USAGE IN THE ABSTRACT, TITLE, KEYWORDS, AND/OR REFERENCES (n_R = 19)

3.1.2 The Mystery of “Ethical Considerations”

A common theme was the use of the terms equity, ethics, or justice in ways that were not central to the thesis, results, or discussions of the paper. In other words, these terms can best be described in most cases as well-meaning “add ons.” For example, papers often mentioned “ethical considerations” without describing what the considerations were. In other cases, the EEJ term was mentioned in the abstract and/or conclusion but not anywhere in the body of the text. This result reveals one way in which EEJ terms are represented and included in engineering design literature.

There were also papers that had a clear motivation for why the authors viewed ethics, equity, and justice to be integral to the theme of their research, but they approached these topics through exclusively commentary without analysis or discussion of data. For example, one paper presented a strong ethical motivation for improving the reliability of environmental technology [27]. However, there was an absence of research-based evidence throughout the paper, demonstrating a lack of scientific understanding of the terminology used; the authors present an unsupported equation that resembles a thought experiment rather than a tested and validated mathematical formula. Additionally, they include frequent references to religious arguments, such as claiming that “a closer, in depth historical analysis of the problem of environmental pollution over time clearly proves that it is, first and foremost, an ethical problem, a moral crisis of the human spirit, which began with the Fall of the Protoplasts Adam and Eve from Paradise” [27] instead of citable scientific claims.

3.1.3 Sustainability as a Substitute for Justice

Considerations related to sustainability, the environment, and energy equity were recurring themes in our sample of reviewed papers. However, in many cases, the authors used sustainability interchangeably with ethics without drawing a clear connection between the two. While sustainability is a good entry point for ethics, equity, and justice analyses, it is important to recognize that a technology could be sustainable without being ethical, equitable, or just. For instance, creating eco-friendly water bottles that are designed to use less plastic but use unethical and unfair labor practices during their manufacturing process in order to keep costs low for consumers would be sustainable without being ethical.

One paper claims in the abstract that “sustainability, ethics, health, and safety features were considered in relation to the design specifications” [18]. However, the word “ethics” only appears once in the full text, again to say that “In addition to technical details and functionality, the design also included consideration for sustainability, ethics, health, safety, socio-economic, and cultural issues...” [18]. The text meaningfully engages with sustainability but does not discuss ethics beyond claiming that ethics were considered. In this case, the authors appear to be using the terms sustainability and ethics interchangeably. A first step here would be to more meaningfully discuss how the designers considered ethics in relation to the design specifications.

Another category of papers understood that prioritizing sustainability was an ethical choice. One paper described a case study of using an optimization strategy to choose which town to locate a manufacturing plant in to “provide financial savings, reduced carbon emissions and lay the groundwork for a more ethical business strategy” [28]. In this case, they are interpreting reduced carbon emissions (a measurable component of sustainability) as a more ethical business strategy. This does not take equity into consideration but would be strengthened by doing so. The towns are all treated the same despite having different communities living there who would be impacted by the decision (potentially by increased job availability or displacement). This category of papers could be taken a step further by meaningfully engaging with equity by addressing how different groups might have different constraints and how that would influence the design or optimization process.

Other papers meaningfully engaged with equity but, on observing inequitable outcomes, did not identify measures to correct them – thus not actively taking a pro-justice stance. For instance, one paper explicitly recognized that women and children are the ones doing the work of collecting fuel and inhaling fumes from cookstoves [26]. However, it doesn’t discuss implications of that insight and how these disproportionate harms are affecting already marginalized groups.

Though each paper need not address all three EEJ terms, the examples provided here are suggestions on how engineering

design researchers who have already begun considering these terms can further their meaningful engagement with each topic.

3.2 RQ2: Change in representation of EEJ Terms in the Literature Over Time

As shown in Figure 4, the number of papers using these terms has considerably increased in the last 20+ years from only 1 paper before 2000 to 8 papers within the most recent 5-year period. Ethics has been the primary term used, but it is especially notable that the prevalence of “equity” and “justice” has also increased over this period. This mirrors our expectation as the prevalence of these topics in cultural awareness and discourse has been increasing over time. Ethics has long been recognized as relevant to engineering but it appears that equity and justice are also slowly becoming part of the engineer’s vernacular.

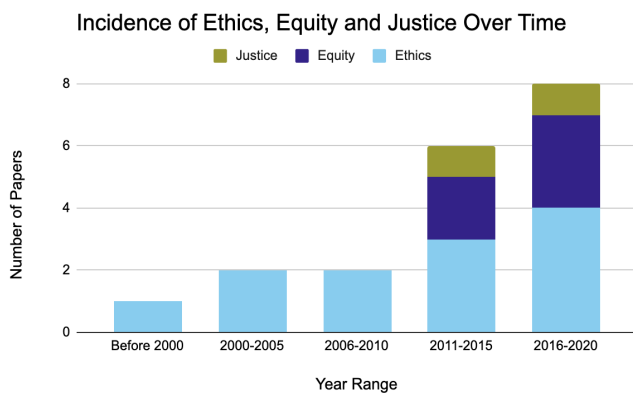


FIGURE 4: NUMBER OF PAPERS ($n_R = 19$) USING THE TERMS EQUITY, ETHICS, OR JUSTICE IN THE TITLE, ABSTRACT, OR KEYWORDS OVER TIME. PAPERS ARE BINNED INTO 5 YEAR INCREMENTS.

3.3 RQ3: Presence of EEJ Terms Throughout the Design Process

Table 4 shows our final design stages [29] along with examples and definitions for each stage and the number of papers from the sample ($n_R = 19$) that fit in each stage. Note that education and team formation (marked with an asterix in the table) are not typically considered parts of the design process but are included here as they are related to the planning stages of design and are key in the professional development of an engineer before they begin to design. It is important to acknowledge that these stages are a simplified depiction of the design process, which by its nature, is very iterative and nonlinear across these stages. Instead, these stages are considered as phases of completeness of design work rather than the exact order in which design work proceeds. Additionally, we recognize that many papers could contain content related to more than one stage of the design process. However, for this analysis, we categorized each paper into one primary stage of the design process based on its

primary focus. Note that not all of the examples used in Table 4 are considered “meaningful” uses of the term based on our analysis as some stages of the design process did not have any papers that meaningfully included the EEJ topics.

Figure 5 shows a graph of which stage of the design process was the focus of each paper and whether or not it meaningfully included one of our key terms. There is not a heavy bias toward any phase of the design process. Several systems optimization/analysis papers included the terms but did not integrate them meaningfully.

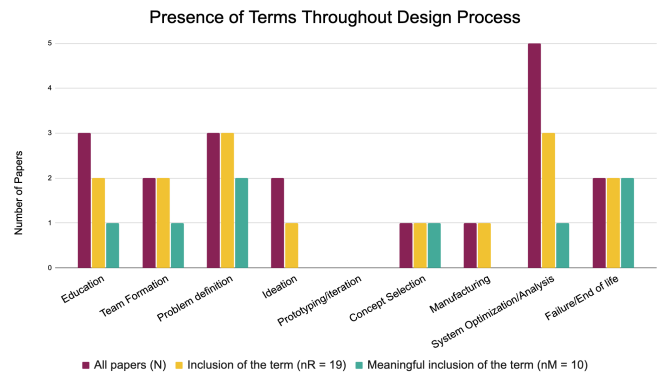


FIGURE 5: NUMBER OF PAPERS AT EACH STAGE OF THE DESIGN PROCESS (FOR N , n_R , AND n_M FROM LEFT TO RIGHT)

3.4 RQ 4: Motivation for Inclusion of EEJ Terms in the Literature

We also tracked motivations for featuring EEJ terms in papers and the context in which they were brought up, whether it was to prevent future failures, protect the environment, or maximize profits, with results summarized in Table 5. Note that these represent only a subset of potential motivating reasons, as were present in the dataset. There should be many other motivations for future papers in this field that meaningfully include EEJ terms and are aligned with the Design Justice framework.

Environment/sustainability was the motivation category with the most papers [18,22,27,34,36], followed by teaching ethics/equity/justice [30,32,37,38]. Two papers each focused on ethics in experiments [23,31], financial incentives [25,28], inclusion of a historically marginalized group [21,33], or energy equity (also closely linked with sustainability) [26,39]. Avoiding catastrophe [24] and understanding technology [35] were the motivators for one paper each.

TABLE 4: OUR DEFINITIONS FOR EACH STAGE OF THE DESIGN PROCESS PAIRED WITH A REPRESENTATIVE EXAMPLE FROM OUR SAMPLE OF PAPERS AND THE NUMBER OF PAPERS FROM THE SAMPLE ($n_R = 19$) THAT FIT IN EACH STAGE. NOTE THAT THE PROTOTYPING/ITERATION EXAMPLE DOES NOT COME FROM ONE OF THE PAPERS WITHIN THE SAMPLE BUT WAS INCLUDED AS A CATEGORY DUE TO ITS WELL-RECOGNIZED IMPORTANCE AS A STAGE OF THE DESIGN PROCESS. CATEGORIES MARKED WITH AN ASTERISK (*) ARE NOT TYPICALLY CONSIDERED STEPS OF THE DESIGN PROCESS BUT ARE RELATED TO THE PLANNING STAGES OF DESIGN AND THE PROFESSIONAL DEVELOPMENT OF DESIGNERS.

Stage of Design Process	Definition	Example	Number of Papers in Each Stage ($n_R = 19$)
Education*	The process of training current or prospective engineers in a technique, method, or discipline before a specific problem is defined.	A college engineering course that encourages students to think of the ethical implications of the product they are designing (i.e. [30]).	3
Team Formation*	The act of assembling a group of people with the intent of later performing a design task together	A study on using Jungian personality type to organize design teams with maximal productivity (i.e. [31]).	2
Problem definition (design requirements)	The determination and declaration of goals and constraints for a product, system, or concept.	The act of designing a “social justice scorecard” to quantify the impact of engineered products (i.e. [32]).	3
Ideation	The process of coming up with ideas that aim to solve a predetermined goal while meeting certain constraints	Participants in an experiment are challenged to generate ideas for an inclusive product design (i.e. [33]).	2
Prototyping/ Iteration	Constructing models of low or medium fidelity ideas to test whether they achieve the intended results and meet constraints. This narrows down the set of potential design ideas before the selection of a final concept.	A toy company tests three product mock-ups with families from a variety of economic backgrounds to help decide which one to take to development.	0
Concept Selection	The decision to pursue a design idea to production.	A proposed energy system for a developing nation is weighed against other options and ultimately chosen to balance the needs of stakeholders, costs, and environmental impact [25].	1
Manufacturing	Production of a high-fidelity design	An assessment of how makerspaces will contribute to sustainable and equitable manufacturing (i.e. [34]).	1
System Optimization/ Analysis (after product is in use)	The study of a preconceived design or system in order to understand how to make it better. This focuses on the characteristics displayed when the design or system is functioning (whether as intended or not) rather than its end of life.	An analysis of the ethical implications of the asymmetry of information between engineers and data scientists (i.e. [35]).	5
Failure/ End of life	The study of a design after wear, breakage, disposal, or catastrophe in order to understand why it failed and how to prevent this from occurring again.	A cost-benefit analysis of disclosing corporate misconduct or an engineering accident to the public (i.e. [25]).	2

TABLE 5: OUR DEFINITIONS FOR EACH MOTIVATING REASON ALONG WITH A REPRESENTATIVE EXAMPLE FOR EACH AND THE NUMBER OF PAPERS FROM THE SAMPLE ($n_R = 19$) WITH THIS MOTIVATION.

Motivating Reason	Definition	Example	Number of Papers ($n_R = 19$) with this Motivation
Avoid catastrophe	Ethics, equity, and/or justice are considered to improve safety, prevent human harm, or avoid calamity.	Analyzing a roller coaster accident to more effectively avoid similar situations in the future (i.e. [24]).	1
Ethics in experiments	Ethics is mentioned as a means of getting research methods approved; alternatively, a study or experiment is analyzed for encroaching on ethical principles.	Studying ethical methods of augmenting creativity as an alternative to neurostimulation (i.e. [23]).	2
Inclusion of a historically marginalized group	Ethics, equity, and/or justice are considered in order to provide a technology, service, or opportunity to a traditionally underrepresented or underserved group.	Strengthening the link between engineering and community service as an attempt to increase the participation of women in STEM (i.e. [21]).	2
Financial	Ethics, equity, and/or justice are mentioned as a factor of a cost-benefit analysis, where inclusion of such concepts is or is not economical.	Attempting to minimize product distribution costs while not compromising ethicality (i.e. [28]).	2
Environment/Sustainability	Ethics, equity, and justice are considered as a means of bettering the natural environment or in order to make a system or process more sustainable.	Promoting closed loop design as a response to resource exhaustion and dwindling landfill real estate (i.e. [36]).	5
Teaching Ethics/Equity/Justice	Ethics, equity, and justice are considered in their own right and are discussed with the intention of furthering the awareness, understanding, and implementation of them.	Development of a tool to better understand and promote ethical decision making (i.e. [37]).	4
Energy Equity	Equity is discussed as a framework of ensuring more equal access to energy and electricity; in some ways similar to sustainability, but with a human focus.	Incorporating the social and demographic conditions of users into energy distribution models to ensure the profit of the owner does not outweigh the needs of the users (i.e. [38]).	2
Understanding Technology	Ethics, equity, and/or justice is discussed as a manner of clarifying how a tool can be best used.	Narrowing the gap in understanding between engineers and data scientists in creating and interpreting models [i.e. 34]).	1

4. ENGINEERING DESIGN RECOMMENDATIONS

From the memos and reflections on specific papers, we crafted seven recommendations to help promote justice and equity advocacy in engineering design. These recommendations follow several themes that emerged from the results: a lack of co-designers in design processes, a promise of social impact, focus on educational settings, religious commentary, systems optimization, and a hesitation to pro-justice positionality. One common theme was the **lack of including members of the community, users, or clients** being designed for as co-designers. Additionally, several papers mentioned stakeholders without including feedback from stakeholders as a step in the

process. *We recommend stakeholders and community members be included as key parts of the design process through co-designer roles (Recommendation 1).* Another theme centered on the **promise of social impact** in engineering. One paper described using social impact projects to draw women to engineering but also described how even some professional women engineers did not see social impact as part of their work [21]. *Engineering design has marketed social impact projects as a way to attract people to engineering fields, though further work needs to be done to meaningfully embed social impact as a key priority and core foundation of engineering practice (Recommendation 2).* Several papers also focused on another

theme: **educational settings**. *An overall recommendation is to give students in educational settings opportunities to pick projects that are more meaningful to a broader group (Recommendation 3). Additionally, it is important to avoid generalizations about the group you are trying to include or help (Recommendation 4).* For instance, one paper encouraging women to participate in STEM made broad generalizations about girls disliking sports and weaponry being factors that prevented them from wanting to get involved in STEM [21]. Papers in educational settings also had some problematic practices with regard to norms around diversity. One paper from 2008 consistently used he/him or Mr. (such as a team role being called “Mr. Brains”) as “generic” terms [30]. While this may have been aligned with norms of gendered language from 2008, a woman on the team may have felt uncomfortable with her team role being called “Mr. Brains” or may have shied away from such a role as a result. We can learn from this to ensure that our current educational practices are more inclusive. Another paper stated that it was possible to “compensate for a lack of diversity in [a] team if they can consciously accomplish their roles even though the roles are expected roles that are foreign to their own preferences or personality traits,” [31]. Another surprising theme was **religious commentary** being portrayed as ethics (though it was only present in one paper within the full analysis, it merits discussion) [27,40]. Conflating ethics with religion is a dangerous precedent to set within the academic research community because this may alienate and exclude researchers and students whose own beliefs are not aligned with the religious frameworks being claimed as truth by authors. All researchers, regardless of their religious beliefs, should feel compelled and empowered to consider EEJ topics in their work, without feeling that religion under the guise of ethics is required. Secondly, this should be avoided because research papers that include EEJ terms without substantial grounding in literature on the topics take credibility and momentum away from research that responsibly integrates these topics. *This non-substantial type of content that portrays religion as synonymous with ethics could lead to exclusionary practices in the context of engineering design literature and should be flagged by peer reviewers when accepting papers for publication (Recommendation 5).* **Systems optimization** was a theme found in several of the papers. However, these papers typically did not include considerations related to what is being designed. For instance, is it important to optimize a factory’s production if the product the factory is producing is harmful? Additionally, these optimization problems did not take into consideration differences in local communities, who is being impacted by the results of the optimization, and so on. For instance, when deciding where to place a factory, they did not take into consideration who would gain or lose jobs, who would potentially live in an area with more pollution, and so on. Several papers focused on financial incentives for ethics (such as disclosing failures [25]). The engineering design community must discuss if financial incentives should be the primary motivator for considering ethics in engineering. In some cases, ethical considerations were mentioned but simply treated as a

quantified standalone factor within a cost-benefit analysis, which could result in “optimal” outcomes that encourage engineers to behave unethically [25,28]. *Optimization related studies should explicitly discuss these tradeoffs and how they are determining whose needs to prioritize or how they are quantifying factors such as ethics (Recommendation 6).*

Several papers shied away from taking a **pro-justice positionality** within the work. Contextualizing problems with ethics is a good start, but it is not an end in and of itself. *Engineers and researchers must take the step from ethics to equity and justice by prioritizing stakeholders who are disproportionately impacted by designs and actively taking a stance on what is just when engaging in design in multiple and varied contexts (Recommendation 7).* One paper suggests that using students for a study on risk management as a limitation due to students’ unawareness- these authors might consider making a case for students to be taught this crucial content. Some papers criticize ethics gone wrong, such as in the instance of disasters [24]. However, they do not typically provide suggestions for avoiding ethical dilemmas earlier in the process or actively striving for justice when designing. Similarly, many papers use vague terminology regarding ethical considerations; this is unhelpful and should instead be replaced with direct information about what ethical considerations are and why they were prioritized. Interestingly, one paper that delineated ethical and unethical actions showed an example of ethics questions used for employee training. They used an example of an engineer using the framework of work for one client for another client as an example of unethical behavior. This is an ethical issue only if you assume that we are accepting the framework of capitalism where a client owns every part of an idea once it has been used in the context of their project- instead, this could be framed as broadening access and building on past successes.

Researchers should also consider taking the step from recognizing equity issues to advocating for justice by taking a stance within their work on which stakeholders’ needs should be prioritized and why. While this is the ideal positioning for engineering design researchers, we recognize that not all researchers will be comfortable with taking a normative/justice-oriented stand, even if they present an analysis of inequities, because they may not know what the solutions are or may not think that it is their place to offer such solutions. These solutions may also be better prescribed by others with more expertise of knowledge in the space, but engineering design researchers can still engage in these spaces collaboratively with experts in these areas to take a stance in their research and advocate for justice. Simultaneously, the field at large should allow and encourage engineers and designers to work with scholars who are experts in considering ethics, equity, and justice in design. This work can be daunting- in the next section, we provide a new framework and typology to guide designers and design researchers through this process.

5. AN EEJ TYPOLOGY AND FRAMEWORK FOR ENGINEERING DESIGN AND RESEARCH

Table 6 expands Constanza-Chock's Design Justice framework [10] to incorporate the results from this literature review and form an adapted framework for Engineering Equitable Design and Equitable Design Research. It pairs each design justice topic from the original framework [10] with a design justice question that more broadly describes what that topic is referring to. It then breaks down that question into additional example questions specific to engineering design practice and research.

Three new categories were added to the table (and are shaded in gray) based on common themes that surfaced during the literature review. These are sustainability, systems optimization, and education. The table aims to guide designers and design researchers in thoughtfully considering ethics, equity, and justice in their design work. It is not meant to be an exhaustive checklist or collection of questions for designers to engage with, but a starting point to inspire and promote discussions and attention to these areas that can be translated in the future to more thorough and rigorous design process tools

TABLE 6: EXPANDED FRAMEWORK FOR ENGINEERING EQUITABLE DESIGN AND ENGINEERING EQUITABLE DESIGN RESEARCH. ASTERISKED ITEMS (*) ARE ALSO QUESTIONS THAT CAN BE CONSIDERED IN ENGINEERING DESIGN RESEARCH. NEW CATEGORIES ADDED ARE SHADED IN GRAY.

Topic	Design Justice Question	Engineering Equitable Design Questions
<i>Equity</i>	Who gets to do design?	Who is included in the design process as a co-designer? How can we incorporate people and communities into the design processes through participatory techniques such as participatory design, co-design, or citizen science?*
<i>Beneficiaries</i>	Who do we design for or with?	What is the background and identity (race, socioeconomic class, ethnicity, gender, disability, and sexuality) of those who are included in the design process? What backgrounds and identities are not represented?*
<i>Values</i>	What values do we encode and reproduce in the objects and systems that we design?	Who is regarded as an expert and why?*
<i>Scope</i>	How do we scope and frame design problems?	Did you take the users' needs into account? Who are the target users and what are their identities and backgrounds? Who is not included as a target user and why?*
<i>Sites</i>	Where do we do design? What design sites are privileged? Which sides are ignored or marginalized? How do we make design sites accessible to those who will be most impacted?	Are there individuals who are not users who may be impacted by the development and use of the design in question? If so, how are their preferences and priorities accounted for in the design or design research process if at all? Do designers recognize the difference between designing for vs. with a group? How do researchers explore and understand the spectrum of users' wants and needs including personalization, adaptability, and flexibility? How are these reflected in the design?*
<i>Ownership, Accountability,</i>	Who owns and profits from design outcomes? What	What (and whose) values, biases, and assumptions are engineers and designers embedding into their designs?*
		Is the design aligned with the customs or cultural values of the intended users? Of non-intended users who may wish to use the product? What practices can researchers incorporate to mitigate the encoding and reproduction of inequitable values in designs and promote the inclusion of equitable and antiracist values?*
		What problem or need informs the design or research of the study or technology? How will this evolve over time? How is the problem and need defined?
		What context (such as resource level, geographical location, etc.) do we design for? Where is the design intended to be used? Where is the artifact being designed? In the lab or in the context they will be deployed? What ways can we transform where we design to make the design sites more accessible for those who will be most impacted?*
		How can communities and people impacted by the technology have greater control in

<i>& Political Economy</i>	social relationships are reproduced by design? How do we move towards community control of design processes?	the design process? Could the design be made open-source? Who will own the intellectual property generated as a result of the design? What are the implications of the potential ownership structures of the intellectual property? How are the profits (if any) from the design distributed? Who will profit from the design? Who has access to this research, its results, and its methods?*
<i>Discourse</i>	What stories do we tell about how things are designed?	How do people describe or discuss the design? What stories do people share about the design and its impact on them? How do stories of the technology differ across people from varied backgrounds or identities that engage with the design?*
<i>Histories</i>	Acknowledging unequal histories and/or historical harms arising from technology design, use, or diffusion.	How has this or related designs been used in the past? What design decisions have historically caused harm?
<i>Sustainability</i>	How do we consider the long-term impact of our designs on the health of the planet?	Does the design process consider sustainability and/or environmental impact as it relates to the object or system being designed? What is the life cycle of the design? What kind of waste might the design produce? What is the impact on the environment of each stage of the design process- from prototyping to manufacturing?
<i>Systems Optimization</i>	How do we consider justice as a parameter when optimizing a design problem?	How are variables being weighted for importance- whose values are encoded in these weights? How are people being considered as variables within an optimization problem? What quantity is being optimized for and why? Who decides this?
<i>Education</i>	How do we teach new generations of engineers to prioritize advancing justice using their design practices?	How are novice designers being trained to consider justice in their work? How are class projects decided on and designed for student design courses? What is considered worthy or unworthy of exploration? Are ethics, equity, or justice explicitly or implicitly prioritized in pedagogy?

6. LIMITATIONS

A major limitation of our work is the exploration of only three words (ethics, equity, and justice) and their variations in three venues (the ASME IDETC-CIE conference, the ASME Journal of Mechanical Design, and Research in Engineering Design). It is entirely possible that design researchers are effectively or implicitly talking about these themes but using other terminology such as “resource constrained design,” “participatory design,” and “value-centered design.” Similarly, a plethora of other words such as “fair,” “diversity,” “underrepresented,” or “inclusive” could be key terms that signal adjacent topics as well, though they were not explored for this study. Our search was also limited to these words being present in the title, abstract, or keyword, reasoning that if these words were present in these places it was a primary focus of the paper, though there could be cases where these words are not mentioned in these areas but a focus of the paper. Engineering design researchers may also be publishing work related to these topics in other venues not captured in this initial literature review.

7. FUTURE WORK

One recurring theme in our search was that themes around sustainability and energy came up frequently. It would be interesting to conduct this analysis on papers about sustainability (using “sustainability” as a keyword) since that may be a more commonly used term within the literature related to the ethos of EEJ terms. Equity and justice, in particular, appear to be relatively new words within the engineering design scholarship- it is possible that earlier papers used other words that were part of the discourse at the time and are related to EEJ topics such as “fair,” “diversity,” “inclusion,” or “poverty.” Similarly, terms such as “accessibility,” “resource-constrained,” “participatory,” and “value-centered” may yield more results that capture the ethos of what we are trying to study. This is a key issue as researchers working on similar topics may be using completely different language and terminology, thus creating intellectual silos which prevent synergistic work from researchers being in conversation and collaboration with each other. There is thus a strong case to be made for better defining what we mean when we think and write

about ethics, equity, and justice in engineering design and research and how this connects to other fields that also engage in similar contexts where fruitful collaborations could occur.

Future work should also expand the range of engineering design venues searched during a review of the literature. These could include (but are not limited to) the International Conference on Engineering Design, the Design Computing and Cognition Conference, Design Studies, the Design Conference, The Journal of Engineering Design, and the Artificial Intelligence in Engineering Design, Analysis, and Manufacturing journal.

Ultimately, ethics, equity, and justice should be studied more deeply in the context of design and engineering. Understanding when, why, and how authors, instructors, and researchers of design integrate EEJ into their work (or refrain from doing so) is critical in engineering a more just society and setting a precedent for others to do the same.

8. CONCLUSIONS

RQ1: How are ethics, equity, and justice represented (or not) in the engineering design literature?

The presence of ethics, equity, and justice is very limited within engineering design literature. These topics have been used somewhat interchangeably, which shows that there is not a consensus within the research community about what the terms mean. The term ethics is used more than equity, which is used more than justice.

RQ2: Has the presence of ethics, equity, and justice in engineering design literature changed over time?

The presence of ethics, equity, and justice in engineering design literature has increased over time. 20 years ago, there were very few papers that mentioned any of these terms in the title, abstract, or keywords. The first few papers including these topics have focused on ethics, but equity and justice appear to be gaining traction in the literature in recent years as well.

RQ3: When in the design process and design research process are ethics/equity/justice considered?

Ethics, equity, and justice are considered throughout the entirety of the design process without significant bias toward any one stage. The terms are mentioned and meaningfully included in the first stages that constitute and lead up to the design process (education, team formation, problem definition, ideation, prototyping/iteration), as often as they are included in the latter stages (concept selection, manufacturing, system optimization/analysis, failure/end of life).

RQ4: What are the motivations for including ethics, equity, and justice in engineering design literature?

Many of these terms are coming up in the context of sustainability and energy considerations as well as in educational settings. Some papers mentioned ethics, equity, and justice as an aside to ensure their research methods were approved. The most meaningful inclusions occurred when researchers were motivated to expand inclusion of historically marginalized groups in engineering or when they were addressing energy inequity.

ACKNOWLEDGEMENTS

We would like to acknowledge all the people who have served as part of our broader Design Justice research team along with those who have advised us on our work along the way: Raechel Walker, Shelly Ben-David, Kimberly Kimura, Paige Lighthammer, Olivia Dias, Barbara Adjei, Marina Santos, Jennifer Zhang, Jana Saadi, Catherine D'Ignazio, Cynthia Breazeal, Julie Shah, David Kaiser, and Sasha Costanza-Chock. We'd also like to thank the MIT d'Arbeloff Fund for Excellence in Education for their funding of our ongoing work. Please note that any opinions, findings, and conclusions/recommendations expressed here are those of the authors and do not necessarily reflect the views of the funders.

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