Design Science

Uncovering potential bias in engineering design: a comparative review of bias research in medicine

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Abstract

Engineering design research has focused on developing and refining methods and evaluating design education in design education, design research and design in practice. One important aspect that is not thoroughly investigated is the influence of bias on design within these spaces of design. Bias is known to impact the interpretation of information, decision-making and practices in all areas. These factors are vital in engineering design education, practice and research, emphasizing the importance of investigating bias. The first goal of this study is to highlight and synthesize existing bias research in design education, research and practice. The second goal is to identify areas where bias may be under-researched or under-reported in design. To achieve these goals, a comparative analysis is performed against a comparable field: medicine. Many parallels exist between both fields. Patient–provider and designer–end-user relationships are comparable. Medical education is comparable to design education with the cooperative, inquiry-based and integrated learning pedagogy approaches. Lastly, physicians and design engineers both solve cognitively complex systems-oriented problems. Leveraging research on bias in medicine enables us to highlight gaps in engineering design. Recommendations are made to help design researchers address these gaps.

Keywords: Bias in Engineering, Engineering Design, Medical Bias, Bias, Design Bias

Received 06 January 2022
Revised 13 June 2023
Accepted 15 June 2023

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Des. Sci., vol. 9, e17
journals.cambridge.org/dsj
DOI: 10.1017/dsj.2023.17

1. Introduction

Design success is heavily dependent on the interpretation of information, reasoning, and decision-making, making understanding the factors that influence these actions important (Pahl & Beitz 1996; Eppinger & Ulrich 2004; Linsey & Viswanathan 2010). One factor is bias: the tendency to lean in favor or against someone or something and the absence of a neutral viewpoint on the particular situation (Boysen & Vogel 2009; Haselton, Nettle, & Andrews 2015; De Houwer 2019). Bias is known to influence the interpretation of information, decision-making, reasoning and interpersonal relationships (Hewstone, Rubin, & Willis 2002; Boysen & Vogel 2009; Haselton *et al.* 2015; Plews-Ogan *et al.* 2020a). Therefore, a better understanding of bias and its impacts is key to achieving a deeper understanding of engineering design itself.

Bias exists in many forms: implicit, explicit and cognitive (Hewstone *et al.* 2002; Croskerry 2003; Boysen & Vogel 2009; Haselton *et al.* 2015; De Houwer 2019).

Cognitive bias surfaces during the various stages of cognition or mental action, including but not limited to decision-making, reasoning and interpretation of information (Croskerry 2003). Different types of cognitive biases have been described, such as confirmation bias and hindsight bias. Croskerry (2003) details 32 different types of cognitive biases that may lead to diagnosis errors in the medical field (Croskerry 2003). The process of making a medical diagnosis involves considering numerous factors systematically to make a decision (Wagner 1993; de Haes & Bensing 2009; Chandiok & Chaturvedi 2016). Similarly, cognitive activities used in the engineering design process involve systematical considering factors to develop a solution via brainstorming or reflective processes (Seidel & Fixson 2013). These similarities suggest that identified cognitive biases in medicine may exist in engineering design as well. Implicit and explicit bias are seen in the behaviors or actions of the entity or individual demonstrating the bias (Boysen & Vogel 2009; De Houwer 2019). Implicit bias is an unacknowledged action by the individual demonstrating bias (De Houwer 2019). Explicit bias is expressed as overt, intentional actions or expressions by an individual as opposed to the subconscious nature of implicit bias. (Hewstone *et al.* 2002; Boysen & Vogel 2009).

Bias can negatively influence decision-making, suggesting that it also negatively influences key processes in engineering design tasks such as idea generation, concept selection and collaborative decision-making (Boysen & Vogel 2009; Croskerry 2003; Hewstone *et al.* 2002; Howard, Culley, & Dekoninck 2008; Pahl & Beitz 1996). A detailed investigation into bias is crucial to understanding how bias may negatively influence engineering design outcomes. (Croskerry 2003; Moss-Racusin *et al.* 2018; Parks 2018; Plews-Ogan *et al.* 2020a, 2020b) It is more known for bias to have a negative impact; however, understanding and implementing bias can have a positive impact (Xi, Fu, & Yang 2013). Xi *et al.* (2013) explored how leveraging bias into predictive models can improve design outcomes (Xi *et al.* 2013). Similarly, exploring heuristics and biases has played a positive role in idea generation and collaborative decision-making (Kahneman & Tversky 1974). Heuristics are defined as the cognitive pathways or frameworks used to reach a solution (Griffin, Daniel, & Gilovich 2002). Biases, as defined previously, are the tendency to lean in favor or against someone or something and the absence of a neutral viewpoint on the particular situation (Boysen & Vogel 2009; Haselton *et al.* 2015; De Houwer 2019). In relation to heuristics, biases are the errors that influence the heuristics. The scope of this review focuses on biases influencing design outcomes. In addition to design outcomes, bias, both implicit and explicit, can affect interpersonal relationships (Croskerry 2003; Moss-Racusin *et al.* 2018; Parks 2018; Plews-Ogan *et al.* 2020a, 2020b).

Design is heavily dependent on interpersonal relationships because design is conducted by heterogeneous teams with a variety of roles, skills and perspectives, making it important to understand how interpersonal bias may impact design teams (Clemmensen, Ranjan, & Bødker 2018; Elena & Summers 2019; Green 2006; Prabhu *et al.* 2020; Vestergaard, Hauge, & Hansen 2016). The exploration and study of the impacts on interpersonal relationships in design can enable designers to explore mitigation strategies to counter or avoid negative impacts and achieve positive outcomes. However, bias has not been studied and reported extensively in the design literature. Therefore, we turn to medical practice, a field in which bias has been studied in-depth, to provide clues for its presence and influence in design. In the medical field, biases affecting diagnosis, treatment, disease prevention and medical

https://doi.org/10.1017/dsj.2023.17 Published online by Cambridge University Press

research are investigated to mitigate negative health outcomes and improve human health (McGauran *et al.* 2010; Saposnik *et al.* 2016; Baker *et al.* 2017; Plews-Ogan *et al.* 2020a). As the actions, tasks and events in the field of medicine parallel those in the field of engineering design, the similarities enable the use of existing bias research in medicine to guide bias research in engineering design.

The objective of this study is twofold. Aim one is to systematically review the literature on bias in the field of medicine. Aim two is to leverage knowledge gained from existing research on bias in medicine to highlight potential areas where bias may exist in the field of engineering design. The overarching goal of this work is to provide a resource to the engineering design community to support future research investigating the influence of bias, and so this begins with a systematic review of bias research in engineering design to identify gaps. As previously stated, bias can be explicit, implicit or cognitive and show up in interpersonal relations. For this study, different biases that may potentially exist in engineering design are identified from the field of medicine and grouped into three classes: interpersonal, cognitive and other, as seen in Figure 3. The following section details why bias research in the medical field is useful for highlighting potential bias in engineering design and elaborates on the scope of this review. After the background section, the following section details the approach used to collect and synthesize publications on bias in the medical field. The results section connects the medical field to engineering design to pinpoint potential bias in engineering design. The final section summarizes the findings and proposes future research areas and questions regarding bias and its role in engineering design.

2. Background: analogies between the field of medicine and engineering design

Bias is known to influence a person's thought processes and actions. Both explicit and implicit cognitive bias can lead to misinformed decisions and affect interpersonal relationships (Kahneman & Tversky 1974; Lehner *et al.* 1997). Engineering design utilizes highly cognitive and qualitative processes (e.g., decision-making, design thinking and interpersonal relationships in the form of team collaboration), making the process vulnerable to bias. Bias has been explored for decades in psychology and other social sciences (Baron & Hershey 1988; Hewstone *et al.* 2002; Boysen & Vogel 2009; Marshall *et al.* 2013; De Houwer 2019). Medical research has leveraged the field of psychology's bias research to understand the role bias plays in social interactions and decision-making in the medical field (Aberegg, Arkes, & Terry 2006; Levy & Hershey 2008; Stone & Moskowitz 2011; Saposnik *et al.* 2016). The large body of work on bias in medicine can be used as a guide to investigate bias in engineering design to improve design outcomes.

Though the tasks involved in engineering and medicine are not explicitly the same, the themes in medical research, education and practice parallel those in engineering design research, education and practice. Researchers have previously used events in engineering to investigate similar events in medicine and vice versa (Frey & Dym 2006; Stripe *et al.* 2006; Zeltser & Nash 2010). For example, Zeltser and Nash (2010) highlighted teamwork training programs in aviation to provide a conceptual framework for evaluating the effectiveness of teamwork training in medicine (Zeltser & Nash 2010). Aviation teams, design teams and medical teams share similar characteristics in their approaches to risk reduction and the

https://doi.org/10.1017/dsj.2023.17 Published online by Cambridge University Press

importance of interpersonal skills, making the field of medicine an ideal tool for exploring bias in engineering design.

To date, the concept of bias as a potential variable in engineering design is under-recognized and understudied. The similarities between engineering design and the medical domain allow for existing work in the field of medicine to act as a roadmap for a deeper exploration of bias in engineering design (Frey & Dym 2006). High-level similarities between the field of medicine and engineering design can be seen in Figure 1 and are subsequently discussed in further detail.

The history of the fields of medicine and engineering design may be explicitly different in context, but both fields are rooted in the practice of problem-solving. The primary purpose of medicine is to diagnose, treat and prevent diseases and medical ailments. Diagnosis, treatment and prevention are executed in daily practice but also understood and taught via medical research, and education and training of medical providers. The goal is to ultimately provide solutions to health problems using informed techniques and practices. The central goal of the field of medicine parallels the goal of engineering design but in a different context.

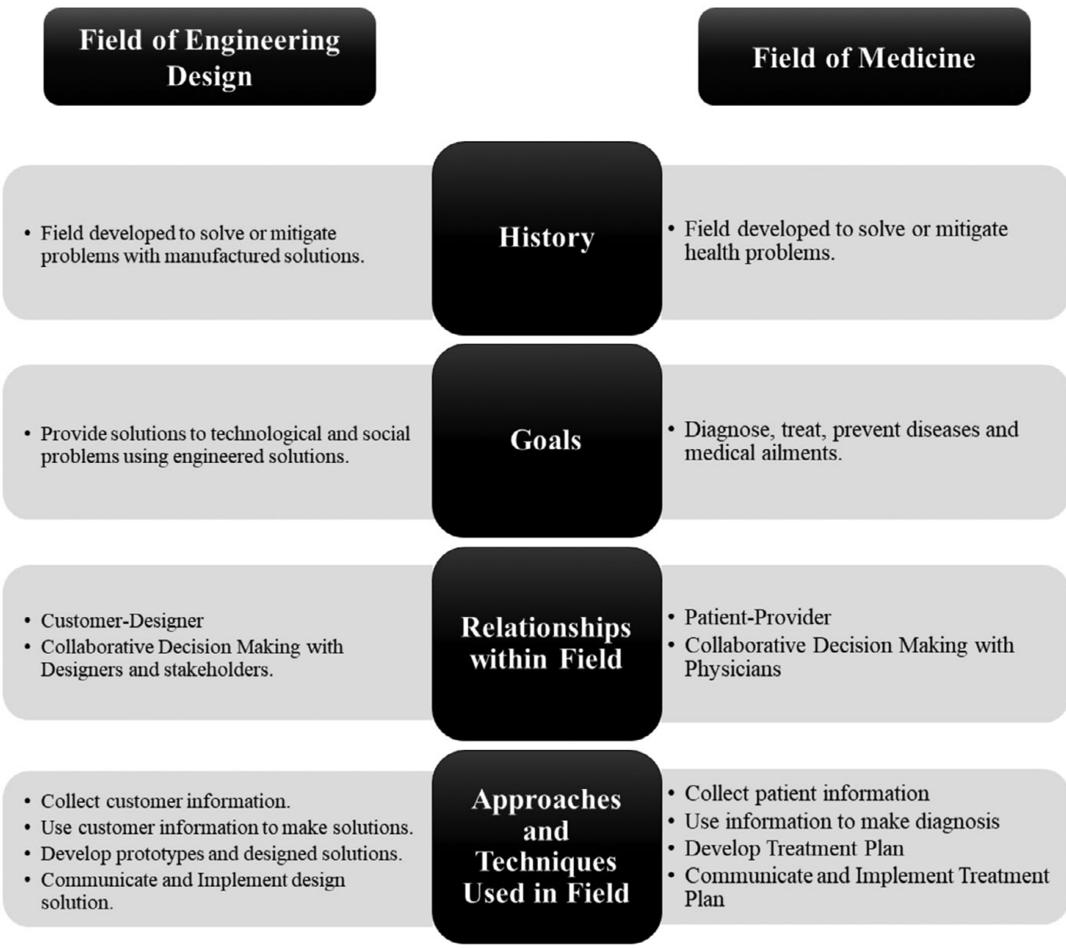

Figure 1. High-level similarities between engineering design and the field of medicine.

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The goal of engineering design is to provide solutions to technological and social problems using informed engineering techniques and practices. To meet this goal, designers also utilize design in practice, design research and design education and training to understand and further improve the field of design.

In addition to common objectives, both fields have similar core relationships; the patient–provider relationship in medicine and the designer–end-user relationship in engineering design. The medical provider, whether a physician, nurse or physician assistant, processes the information provided by the patient and then looks to provide a potential solution. This echoes the interaction that occurs between the designer and the end-user (Frey & Dym 2006). The end-user provides information on their needs, or the designer collects information based on the problem identified and then processes that information to provide a designed solution. In addition to similar approaches to collecting information, medical providers and design engineers have similarities in how they handle the information once collected (de Haes & Bensing 2009). For instance, to provide solutions to group health problems, instead of individual patients, medical providers use datasets to identify trends and investigate solutions that can be applied to larger groups. This occurs in engineering design when designers develop solutions that can be applied to groups of diverse end-users. Finally, both fields share problem-solving techniques. Figure 2 illustrates the parallels between the medical diagnosis

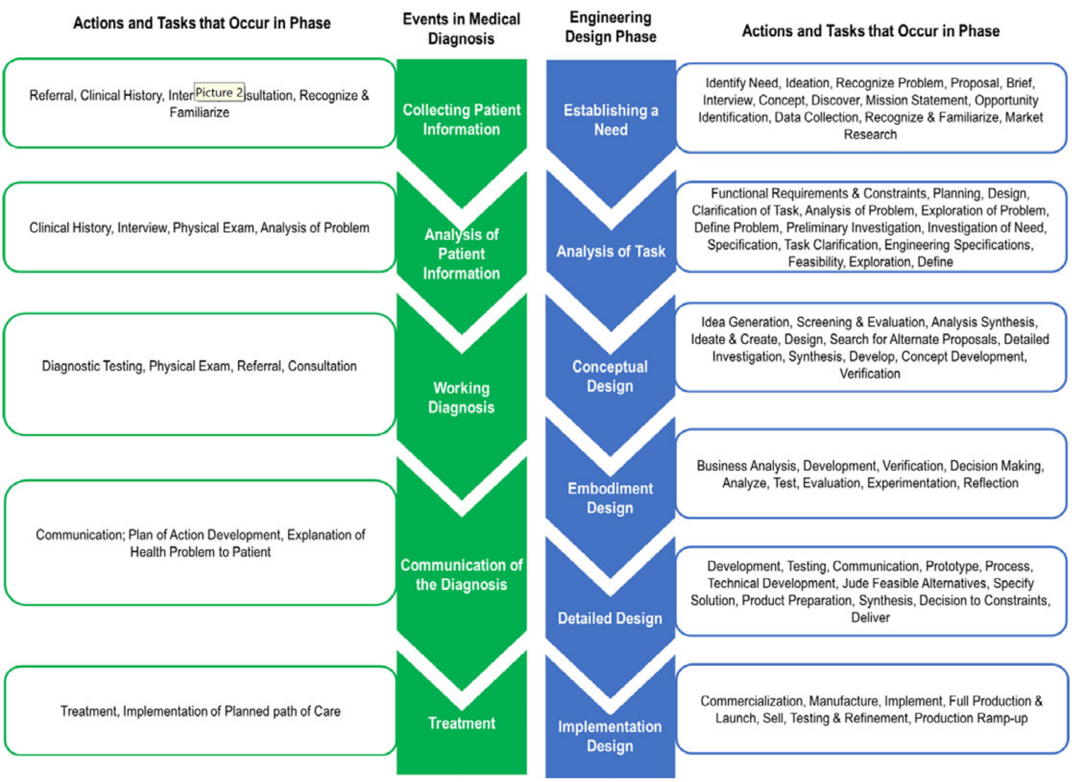

Figure 2. Conceptual process model comparison of medical diagnosis process and the engineering design process (Howard *et al.* 2008; Balogh *et al.* 2015).

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and the design process. The medical diagnosis process is based upon a description provided in the 2015 National Academics Press (Balogh, Miller, & Ball 2015). The engineering design process description is based on the Howard *et al.* (2008) framework for the engineering design process. *Actions and Tasks that Occur in Phase* are defined as events that occur in that phase or the information that may be collected in that phase. For example, *Clinical history* represents an information type that may be collected by a medical practitioner from their patient.

As seen in Figure 2, the engineering design process can be divided into subsequent phases. These phases include *Establishing the need, analysis of task, conceptual design, embodiment design phase, detailed design* and *implementation design.* Many actions and tasks in medical practice parallel ones in engineering design especially with regard to the process physicians use to come to a medical diagnosis. The *establishing the needs* phase is equivalent to when the physician collects information from the patient and other available resources. The *analysis of task* phase equates to when physicians identify both positive and negative findings from the information provided by the patient or the available resources. The *conceptual design phase* is when the project needs and problem space are interpreted, and the designer begins to generate and identify concepts that can be potential solutions. The *embodiment design phase* is when the concepts established are developed into tangible prototypes or solutions. The *detailed design phase* is the phase where the final solution is developed. These phases are not as evidently related to the medical diagnosis process. However, these phases parallel when medical professionals synthesize the findings established from the prior phases into a clinical diagnosis and then use that diagnosis to adopt a plan of action. The final stage, the *implementation design phase*, is when the final design solution is deployed, and the commercialization or application of the solution is executed and monitored. The final phase is similar to when physicians apply their plan of action in response to their diagnosis, most often when the treatment plan is formulated and implemented.

Beyond the methods used in practice, similarities also exist in the education and training approaches used to establish problem-solving methods. Medical providers are trained to address society's health needs (Bloom 1988). Medical providers and design engineers solve problems using skills and techniques that parallel each other. The education and training to learn those problem-solving skills also have similarities, starting with the trajectory of the curriculum. In most curriculums, engineering design is taught at the upper-level undergraduate level, building on previously taught engineering concepts (Emami, Bazzocchi, & Hakima 2020). Some engineering schools introduce engineering design early in the undergraduate curriculum to complement other engineering courses and to familiarize students with engineering design early. Overall, engineering design is intended to enable students to integrate and use engineering skills to solve design problems. In the medical field, students major in STEM or related fields and then integrate and use those skills in medical school. To integrate and use skills, both medical students and students in engineering design participate in training, coursework and projects that have a mixture of cooperative, inquiry and integrated learning pedagogical approaches.

Though there are several similarities between the field of medicine and engineering design, there are differences between the fields that need to be mentioned. In practice, a medical practitioner is more likely to apply evidence-based, standard treatments to develop a diagnosis (Brush, Sherbino, & Norman 2017; Corazza,

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Lenti, & Howdle 2020; Cusimano 1996). In design, a systematic approach is used to collect and deduce information for a design solution (Pahl & Beitz 1996). However, a key difference between the practices applied to determine a diagnosis and develop a design solution is that designers are more likely to implement unconventional solutions. This may be due to another key difference between the fields that the medical field is explicitly higher risk than engineering design. Another key difference is the type of information medical professionals consider when making a diagnosis. Medical professionals collect contextual information, just as designers do to make a design solution. However, medical professionals systematically are more inclined to consider information on emotions and respond to those emotions(de Haes & Bensing 2009). This may be due to the need for them to have a bedside manner with patients. The differences between engineering design and the field of medicine still allow for the comparison of biases in both fields. However, in comparing and identifying biases in engineering based on biases in the field of medicine, it is important to recognize the differences in context to identify how biases may show up.

Other fields more closely related to engineering design, such as software engineering, have studied bias within their field (Mohanani *et al.* 2020). Mohanani *et al.* (2020) systematically reviewed bias in software engineering and identified what bias has been researched. Though Mohanani's work shows bias has been explored in a field that is more closely related to engineering design, he also finds that there have been limited studies on ways to mitigate bias (Mohanani *et al.* 2020). The goal of this work is not only to pinpoint potential bias but to drive future work to find ways to mitigate that bias. Bias research in the field of medicine was used as an analogy for bias in engineering design because some studies in medicine have identified ways to mitigate bias (Benoit *et al.* 2020). In addition to providing ways to mitigate bias, bias research in the field of medicine also explores bias in three foundational areas of medicine: medical research, medical practice and medical education. Limited research exists in niche areas of engineering that cover education or instructional bias, research bias and bias that occurs as a practicing engineer in that specialty. Cognitive bias and bias have been studied extensively in psychology (Hotopf 1958). However, bias in the field of medicine was chosen for this comparison because it has been used as an analogy to engineering design (Frey & Dym 2006) as well as bias research has been studied in three distinct domains; education, research and practice (Capers *et al.* 2017; Green *et al.* 2007; Mendel *et al.* 2011). Engineering design applies to many fields of engineering, so leveraging and encompassing fields such as medicine will highlight the reach of potential bias within the field of engineering design.

3. Review of bias in engineering design

The ultimate goal of this paper is to further drive research on bias in engineering design, driving research to investigate bias, understand its impacts and develop approaches to mitigate bias. To do so, the first part of this review examines bias research in engineering design to paint a picture of how bias has been explored in engineering design. The engineering design space encompasses many fields of engineering. Our review of the existing literature on bias research in engineering design has yielded only a few studies, with the majority of the focus on tool bias and designer bias with concept selection or evaluations (Anderson & Gilbride 2007;

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Gopsill 2018; Gweon *et al.* 2017; Hallihan & Shu 2013; Howard & Borenstein 2018; Jansson & Smith 1991; Khoje *et al.* 2018; Mueller *et al.* 2012; Nelius *et al.* 2020; Ostafichuk & Sibley 2019; Savage *et al.* 1996; Stacey *et al.* 1996; Toh, Strohmetz, & Miller 2016; Zheng, Ritter, & Miller 2018). Zheng *et al.* (2018) investigated the impacts of a concept selection tool on promoting creative ideas and decision-making among designers (Zheng *et al.* 2018). The findings indicate that designers are inclined to select ideas that were highly ranked by design tools only if the concept met their expectations, hinting at the existence of a cognitive bias in decision-making (Zheng *et al.* 2018). This study suggests that bias should be considered when investigating the effects of design tools. Jansson & Smith (1991) investigated if design fixation is measurable (Jansson & Smith 1991). The findings suggest design fixation is measurable and may be influenced by cognitive factors measurable with cognitive science research techniques. Design fixation is an extension of cognitive research that is explored in engineering design (Vasconcelos & Crilly 2016; Crilly 2019) and may benefit from design bias. Mueller *et al.* (2012) investigated why people reject creative ideas and found that a participants' bias against creativity may have interfered with their ability to recognize a creative idea (Mueller *et al.* 2012). Mueller's study demonstrated that participants exhibited a negative bias against creativity when they were uncertain of the final design solution (Mueller *et al.* 2012).

Similar to uncertainty, Savage (1996) explored the impacts of cognitive overload and bias on engineering design and found that there is roughly a 50% chance certain information such as time and cost can influence the design outcome (Savage *et al.* 1996). Similar to Savage's study, Gopsill (2018) looked at how factors may bias design outcomes when it comes to construction kits (Gopsill 2018). These studies point out how design constraints drive solutions but also bias solutions, making it important to understand the extent and impact they bias solutions. Hallihan and Shu (2013) found that confirmation bias influences the evaluation of design research and can contribute to deviation from scientifically accurate conclusions (Hallihan & Shu 2013). Nelius *et al.* (2020) also explored confirmation bias in engineering design by investigating its impact on reasoning and visual attention. The findings from this study show that confirmation bias plays a role in the interpretation of the problem and solution space. These studies show ways bias has been investigated in engineering design but suggest more aspects of engineering design bias exists. Concept selection has been at the forefront of bias research in design due to the importance of selecting the best solutions (Stacey *et al.* 1996; Toh *et al.* 2016). Stacey *et al.* (1996) explored bias from design tools used in concept selections by investigating the use of a design tool that strategically leverages design tool bias for concept selection (Stacey *et al.* 1996). Toh *et al.* (2016) investigated ownership bias in concept selection as a result of the designer's gender (Toh *et al.* 2016). Though it is important to understand the bias impacting concept selection, it is also important to understand where else within the design process and design tasks bias is occurring.

Bias has been explored in feedback in engineering design (Anderson & Gilbride 2007; Gweon *et al.* 2017; Khoje *et al.* 2018; Ostafichuk & Sibley 2019). Ostafichuk and Sibley (2019) confirmed the presence of self-bias and gender bias in student peer evaluations when students evaluated women students more favorably (Ostafichuk & Sibley 2019). Other research in engineering has looked at gender bias in engineering, but there are still a lot of unknowns (Khoje *et al.* 2018).

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Anderson and Gilbride (2007) explored the influence of outreach programs on gender bias and female student consideration for engineering careers (Anderson & Gilbride 2007). Anderson's study shows that outreach does bias female students, ultimately improving consideration for engineering careers (Anderson & Gilbride 2007). Though gender bias was found to exist, statistical methods were used to identify bias instead of validated tests that measure the students' bias (Ostafichuk & Sibley 2019) (Anderson & Gilbride 2007). To combat gender bias, Khoje *et al.* (2018) developed an evaluation framework to evaluate the appropriateness of the design projects (Khoje *et al.* 2018). Khoje's framework is a questionnaire intended to be used by engineering educators to determine the appropriateness of design projects and determine the level of gender bias in the design project (Khoje *et al.* 2018). This questionnaire was developed from a literature review of studies that identify gender bias from a statistical standpoint. Though this framework is beneficial, it would benefit if it tackled bias that were measured from validated models. Gweon *et al.*'s (2017) study also highlights how bias from an instructor may have a negative impact. Gweon *et al.* (2017) explored bias in engineering design differently by looking at bias from instructor feedback in project-based learning and ways to mitigate bias from the instructor (Gweon *et al.* 2017). Leveraging bias to improve design outcomes was explored by Xi *et al.* (2013) in computation design (Xi *et al.* 2013). Xi *et al.* (2013) explored an approach to correct model predictions used in reliability-based design based on characterized model bias (Xi *et al.* 2013). This study demonstrates how bias can be leveraged to improve design outcomes in the computational design space. Several studies in engineering design have focused on debiasing methods to reduce bias in engineering design (Cheong & Shu 2013; Emmons *et al.* 2018; Kinsey *et al.* 2021; Hancock *et al.* 2022). But there are limited studies that leverage bias to benefit engineering design outcomes outside of computational design.

The existence and influence of bias on engineering design outcomes have been understudied. The engineering design studies reviewed highlight under-researched aspects of bias in engineering design making the need to understand where bias exists that much more important. The lack of bias research in areas outside of designer bias regarding the generated solution and the bias exhibited by design tools highlights the need to improve the understanding of the extent to which bias potentially exists in engineering design. Though existing work is limited, it is demonstrated that bias exists in engineering design. A lot of work has explored bias in the design tools. Work that has explored gender, race or other factors that influence bias used trends in data to support the existence of bias (Anderson & Gilbride 2007; Khoje *et al.* 2018; Ostafichuk & Sibley 2019). However, few studies measure bias with validated tools to identify its existence. Engineering design research in bias shows that understanding what bias exists can help understand how it can be beneficial to design outcomes. This suggests that understanding the existence of bias more extensively from statistical measures of gender, and race, but measuring bias with a validated tool may allow engineers to develop frameworks that mitigates the negative impacts of bias. The field of medicine may act as a blueprint for engineering design to mitigate bias because they use validated measures in addition to statistical measures to identify bias and develop ways to mitigate bias.

Bias has been investigated in engineering design, but there is room to further drive its investigation in engineering design to understand the influence and

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impacts of bias. No framework and general concept of potential bias research in engineering design exist to help drive bias research in the field. To fill this gap, the next portion of this review intends to leverage bias research in medicine to fill this void and understand potential bias research in engineering design. This review focuses on bias in the field of medicine to then identify if the same bias in engineering design may exist. A systematic review of bias in design was not conducted; only a high-level review of bias in design was conducted. The following sections detail the approach used to provide a summary of bias in the medical field while highlighting potential areas in engineering design that might be specifically affected by bias, providing a roadmap for future exploration of bias in engineering design.

4. Literature review approach: leveraging bias research in the field of medicine to pinpoint potential bias in engineering design

The aim of this study is twofold; systematically review the literature on bias in the field of medicine, and then use the bias research to highlight potential areas where bias may exist in the field of engineering design. To address both aims of our study two reviews of the literature were conducted:

1. Studies investigating the presence, context and mitigation of bias in the field of medicine were reviewed and findings were extrapolated to the field of engineering design.
2. Studies of bias in engineering design were selected to summarize existing research and highlight potential areas where bias may exist.

To meet the overarching goal of the study of providing a framework for future bias research in engineering design, it is important to conduct a review of existing bias research in engineering design. This highlights what research has been conducted in engineering design to not only establish what bias is known in engineering design but also use research in medicine to pinpoint areas that may be unknown gaps. This allows one to indicate the gaps in bias research in engineering design. To outline existing bias in engineering design, a qualitative review of bias research in the field of medicine is conducted. Using bias research in the field of medicine, the potential bias in engineering design was highlighted by aligning tasks, actions and events that are similar in both fields. Research publications on bias in the field of medicine were collected and reviewed for the study. In the medical field, bias can be exhibited by the physician(s) to the patient(s), among physicians and medical providers, and by the patient(s) to the medical provider(s). For the scope of this study, only bias demonstrated by medical physicians, medical professionals and/or medical resources were considered. The following section details the study approach used. The following sections detail the systematic search, screening, selection and review process.

4.1. Literature search

The first aim of this study was to systematically review publications on bias in the field of medicine by pinpointing publications that documented events and tasks in the field of medicine where bias is present. To collect published literature on bias in

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medicine, the Penn State University Libraries and PubMed research database search engines were used. Several search terms were used to search for publications within the databases. The search teams used included "bias in medicine", "bias in medical decision-making", "bias in medical diagnosis", "medical bias", "bias", "medical research bias" and "physician bias". The PubMed search resulted in over 60,000 results, but the Penn State Libraries broad database search resulted in over 1 million hits.

4.2. Screening of literature

The resulting journal publications were screened for the study in the order they resulted from the search, based on the default "relevance" order in the search engine. The first screening of the literature consisted of screening study titles. The titles of the resulting journal articles were screened to ensure that they indicated a specific type of bias and a specific context in which the bias occurred. Titles that mentioned the bias at the focus of the study, as well as the action, event or task where the bias occurs, were selected. From there, the abstracts of the selected publications were screened for study specifications. The criteria for screening abstracts were that the abstract needed to (1) identify that the objective of the study was to investigate bias, (2) indicate that bias was measured in some way in the study, (3) describe the context, including the action, task and/or event, where the bias investigated in the study was identified, and (4) state the impact(s) the investigated bias has on an identified area within the field. Publications that did not fit these criteria were omitted. These criteria were established to ensure that the literature included in the review contained sufficient information to support subsequent comparison and analysis. Due to the large number of studies resulting from the search, studies that investigated the same bias in similar medical events, actions and/or tasks were not considered. This was done to allow for unique occurrences of bias to be highlighted while not over-saturating the data reviewed in the analysis. The remaining publications were screened by reading the full publications.

4.3. Data extracted from publications on bias in the field of medicine

For publications that satisfied the title and abstract criteria, data was extracted to provide context and address the first aim of the study as well as to begin to address the second aim of the study. The types of extracted data are enumerated and defined in Table 1. In addition to this information, the citation information, such as the author, publication year and publication entity, was collected.

The terms listed in the study were used by the author to provide a quasi-framework for each of the studies reviewed in the literature survey. For the scope of this review, *Investigated Bias* or *Used Bias to Interpret Data* is defined as whether the study investigated bias and the impacts of bias or used bias to interpret data findings. *Investigated Bias* means that the study investigated if bias exists in given situations, scenarios or cases. Oftentimes, these studies used validated tools to measure bias. These studies also may have looked at the outcomes of different biases. *Used Bias to Interpret Data* is defined, in the scope of this review, which means the study used known factors that lead to bias, such as race, gender and

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Table 1. Definition of data extraction categories.

Data extraction category	Definition
Bias Category	*The classification of the bias investigated; Interpersonal or cognitive).*
Bias Investigated	*The name of the bias that was investigated.*
Field	*The research area; i.e., medical research.*
Investigated Bias or Used Bias to Interpret Data	*Whether the study investigated bias and the impacts of bias or used bias to interpret data findings.*
Study Design	*The framework, or research approach that was used to collect and analyze data on variables specified in a particular research problem.*
Context	*The circumstances or setting for the occurrence of bias that was investigated.*
Event, Action, and/or Task Investigated	*The actual occurrence of the bias or where the bias investigated happens.*
Variables Investigated	*The aspect that is investigated in the study.*
Variable Manipulated	*The aspect that is altered in the study.*
Method	*The procedure used to execute the study or investigate bias.*
Measure for Bias	*The metric used to quantify or assign a quality to the bias investigated.*
Data Collected	*The values, qualities and/or information collected in the study for analysis.*
Analysis of Data	*The method used to interpret and/or provide an explanation for the data.*
Bias Agent	*Entity demonstrating the bias.*
Bias Recipient	*The entity on the receiving end of the bias.*
Finding	*The new knowledge presented from the study that resulted from the data collection and analysis.*

experience, to identify any trends in data. The *Bias Agent* is used to identify the entity performing the bias and the *Bias Recipient* is used to identify the entity impacted by the bias.

4.4. Data analysis: identifying potential bias in engineering design

Using data from Table 1, which was extracted from medical publications, paralleling scenarios were established for the field of engineering design. This was done using the "*Field*" data, the "*Context*" data, and the "*Event, Action, and/or Task Investigated*" data. The "*Field*" category from Table 1 was used as a high-level category to identify scenarios in engineering design. The three high-level *Fields* used were medical research, medical education and medical practice. These fields parallel engineering design research, design education and design in practice domains. The data extracted as "*Context*" and "*Event, Action, and/or Task Investigated"* were then used to identify similar scenarios in the field of engineering design education, research and engineering design in practice. The events, actions and tasks in engineering design education and research that paralleled the cases in medical education and research were identified. Once identified, the context for

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where this bias may occur in engineering design education and research was also identified. To address the second focus of the study, the gaps in current engineering design research, a search of engineering design research was conducted to establish the extent to which the bias has been investigated and summarized.

The second aim of the paper is to leverage knowledge gained from existing research on bias in medicine to highlight potential areas where bias may exist in the field of engineering design. The overarching goal of the paper is to provide a resource to the engineering design community that helps researchers understand the state of bias research in engineering design and the potential for furthering the understanding of that phenomenon. Toward that goal, the final section of this paper identifies where bias may exist in engineering design and subsequently generates strong hypotheses for future engineering design research to investigate bias for understanding and mitigation.

5. Results

5.1. Selected literature on bias in the field of medicine

For the systematic review of bias in the field of medicine, 30 unique publications were identified. Details for each publication, including *journal*, *title*, *author and date*, domain (*education, research and/or in practice), bias agent*, *bias recipient*, *context*, *event, action and/or task investigated*, and *study design* are listed in Table 2 in the Appendix. Given the parallel relationship between engineering design and medicine, these studies were analyzed to identify where and what bias may exist in the field of engineering design.

5.2. Potential bias in engineering design

The evaluation of selected publications on bias in the field of medicine was organized within three domains of reported bias studies: medical education, medical practice and medical research. Findings from the selected publications were categorized within at least one of these three domains based on the context of the study and the event, action and/or task investigated. These three domains served as a framework to place and investigate potential bias in engineering design. Any action, event or task occurring in the process of education and training of medical professionals was considered when extracting bias in medical education. Bias occurring in the following areas of medical education was considered for this study: textbooks and training tools, the recruitment and admissions process, as well as the educational curriculum. The medical practice domain encompasses any duties and tasks the medical providers utilize while executing their role as a provider. Lastly, the medical research domain includes tasks involved in funding, conducting, presenting and publishing research. Based on the described intersection of the medical field and engineering design, some tasks may be reflected in multiple domains. Data in these three domains are presented as parallels to engineering design to highlight reported bias.

Figure 3 depicts bias present in education, practice and research for both engineering design and medicine fields based on the articles reviewed in the literature survey. Bias presence is divided into three categories, interpersonal, cognitive and other. Indicators in the graphic highlight where bias is known to

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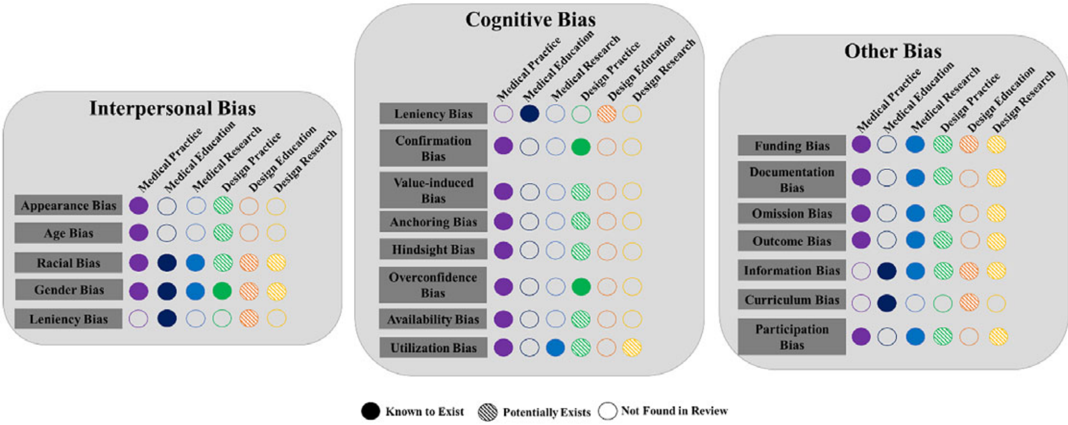

Figure 3. Conceptual diagram of bias present in education, practice and research for the field of medicine and engineering design. (The different colors are to differentiate the column).

occur in medicine and where bias potentially exists in similar areas in engineering design. It is also indicated where bias may potentially exist in engineering design based on known bias in the field of medicine because this review compared the two fields. Known bias, reported in a publication is indicated by a solid, filled circle in Figure 3. An empty circle does not mean bias does not exist; it means the bias was not identified in the comparison made in this review. A hatched circle indicates that the bias was identified and reported in a publication in the field of medicine and, based on a similar context, potentially exists in the field of engineering design. The subsequent sections summarize these findings in further detail. Specifically, comparisons are made in terms of education, practice and research.

5.2.1. Comparing medical education & engineering design education

Education, in the scope of medical education and engineering design education, includes tasks from admission into an educational program to acting as a faculty member in educational programs. Bias has been described and identified in medical school admissions (Griffin & Wilson 2010; Capers *et al.* 2017). Prompted by a lack of diversity in medical schools, Capers *et al.* (2017) investigated racial bias in medical school admissions and found that admissions committee members demonstrated an implicit white preference (Capers *et al.* 2017). The admission committee members included faculty and students. The findings showed that regardless of gender or role, all committee members demonstrated this white preference bias implicitly but not explicitly. While the format of the admission process in engineering design differs from medical school admissions, bias may also exist in the application and admittance process of engineering programs. An implicit racial bias may exist in the admissions procedures or admissions committees of engineering programs, impacting the diversity of engineering designers. The implicit white preference racial bias was found to be one of the factors that influence diversity in medical school. Capers *et al.* (2017) noted that the academic class admitted after the Implicit Association Test (IAT) intervention was the most

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diverse in the school's history, supporting the influence of racial bias on diversity in education.

The reported white preference by admission committees is reflected in the interviews conducted for admission into medical programs (Griffin & Wilson 2010). During the admissions process for medical school, applicants undergo multiple mini-interviews. Griffin & Wilson (2010) found that the interviewers show leniency interviewer bias toward interviewees based on the personality and gender of the interviewee (Griffin & Wilson 2010) by being more permissive and sparing toward the interviewee (Griffin & Wilson 2010). This bias is reflected in the interviewer's evaluations of the interview even though the bias demonstrated was small. Evaluations such as these may occur in interviews of applicants for engineering programs. Though interviewing may not occur in some programs, leniency bias can also show up in the review of applicant materials. Interviewer leniency bias for interviewees of similar gender and personalities can cause engineering programs to lack diversity based on gender as well as mindsets. Engineering and STEM programs are known for a lack of diversity and inclusion (Briggs 2017; Jones *et al.* 2018; Botella *et al.* 2019). For 2019, the American Society of Engineering Education reported that 18.1% of tenured/tenure-track STEM faculty positions were held by women and 2.5% were held by African Americans (Roy 2020). Accounting for leniency interviewer bias and implicit preference bias may shine a light on ways to achieve a more diverse population of engineers (Wulf 1999; Du & Kolmos 2009; Daly *et al.* 2016). Biases in the engineering programs not only impact the students but also the faculty (Moss-Racusin *et al.* 2018). Gender and racial bias, as well as leniency bias toward a specific gender, impact women and racially marginalized engineers, affecting their sense of belonging and readiness for participation (Moss-Racusin *et al.* 2018). Therefore, it is important to be aware of any biases that occur in the admissions process of engineering design programs, but also any bias that occurs among faculty in those programs.

Another area in education where bias may exist is the curriculum (Dijkstra, Verdonk, & Lagro-Janssen 2008; Schofferman 2015; Benoit *et al.* 2020). Dijkstra *et al.* (2008) recognized that gender bias existed in the field of medicine, and therefore investigated if it was reflected in medical textbooks (Dijkstra *et al.* 2008). It was found that medical textbooks show gender bias, lacking gender-specific body and social environment information relevant to good medical practice. Textbooks act as resources for learning, but they also act as datasets used to make informed medical decisions and conclusions. In engineering design, bias may exist in the design textbooks used. Textbooks are used to teach engineering design and also act as a resource that provides tools for executing engineering design (Pahl & Beitz 1996; Otto & Wood 2000; Dieter & Schmidt 2013). A bias in textbooks could lead to biased design practices and a limited perspective when conducting design. A gender bias may exist in engineering design textbooks as well, and this should be assessed in further detail.

In addition to textbooks, Benoit *et al.* (2020) demonstrated that bias exists in medical training (Benoit *et al.* 2020). When discussing normal and healthy bodies in medical training, white bodies and features were often used which could imply that different bodies are not healthy. For example, in a lecture on gum health, pink gums were provided as an example of healthy gums. However, healthy gums can also be brown or purple in people with darker skin tones. Benoit et al. (2020) sought to provide a framework on how to remove such implicit biases from the

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curriculum. Though engineering design may not use human bodies as the basis of healthy and unhealthy in the way it is used in the medical field, similar scenarios may occur in the engineering design curriculum when referring to customers or end-users of a design solution. When teaching students to design for customers or intended users, it is important to not bias their approaches by providing example design solutions that reflect certain populations. For example, the curriculum should not only provide example design problems and solutions that reflect traditional engineering space because that may bias designers to focus solely on providing a specific and familiar solution but may not fit well within the intended user's environment or expectations. This was the case with crash test dummies for car collision safety testing (Gupta 2021). The test dummy represented an average size white male, resulting in safety data that was inaccurate for drivers of different body types, particularly women. This may show up in methods taught to collect information on the end-user, or methods taught to evaluate the final design, making it important to investigate implicit bias present in design methods. Design methods are crucial in guiding the designer in the design process, so understanding the bias present in the methods can highlight if and why bias exists in design outcomes.

Schofferman (2015) also demonstrated that bias may exist in medical education with the source of bias being industry-funded medical education curriculums (Schofferman 2015). Continuing medical education (CME) programs that are financially supported by industries have the potential to subconsciously bias leadership professionals and educators. This bias can be caused or enhanced by marketing strategies used because industry participants funded by CME programs are more likely to use the sponsoring company's product in training. This can occur at CME programs as well as at CME conferences. Being exposed to specific products in training impacts the participant's or attendee's choice of drugs and devices used in practice, potentially affecting patient care. A similar scenario may occur in engineering design education regarding industry-funded engineering design programs, projects or courses. Industry-funded programs, courses and projects often use content and tools provided by the industry funder. The educational institution may have limited control of the project focus, materials taught, and the design tools and equipment used. Though students often seek out these industry-funded programs or projects, this involvement can unintentionally bias the student designers. Pinzur (2020) also addressed bias in industry-sponsored educational programs, specifically looking at a specialized society that educates medical professionals: the American Orthopaedic Foot & Ankle Society (AOFAS) (Pinzur 2020). Pinzur detailed that within AOFAS educational program presentations, presenters avoided highlighting competitors' products, showing a selection bias in the educational information presented. Before material was presented, there was also selection bias in the papers or presentations accepted, with research being rejected if the committee members disagreed with the treatment advocated, or the device or implant used. Pinzur's study highlights how different education avenues can be biased as well as unintentionally teach bias.

In engineering design education, this bias may occur at industry-sponsored conferences or educational programs. Stakeholders may limit sharing content that does not align with the industry funder, limiting the shared knowledge within the large engineering design community. Conferences and education programs offered at conferences are often the places in the engineering design community where

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students, researchers and educators can network. If the places that act as collaborative educational spaces for engineering design are prone to be biased, this may influence existing biases designers have as well as unintentionally limit the expansion of engineering design. It is important to understand that bias exists in industry-sponsored education programs, on both the small and the large scale. As detailed before, in engineering design education, bias has not been explored as extensively as in medical education. Bias studied in medical education highlights what may influence or induce bias in engineering design education as well as the gaps in engineering design education bias research.

5.2.2. Comparing medical practice & engineering design practice

The second domain explored is the practice of medicine or engineering design. The scope of this study covers actions, tasks and events that occur when practicing medicine or executing engineering design. The process of engineering design can be divided into subsequent phases as seen in Figure 1. Using the established phases in Figure 1, bias in design practice was pinpointed. The *establishing the need phase* is when the designers begin to collect information on the intended user or intended design space to identify the need, problem or scope of the project. In this stage, a lot of information searching, collection and processing occurs, similar to when medical providers take a past medical history or search for information to diagnose a disease. Medical research has identified many biases that may also be found to influence actions and tasks that may show up in the first stage of the design process. In the *establishing needs phase*, the designer is oftentimes interacting directly with the intended end-user, or indirectly by collecting information from resources on the end-user. Bias research in the field of medicine shows that provider bias influences this similar interaction in medical practice: physician–patient interaction and treatment recommendations (Sieverding *et al.* 2018). Sieverding *et al.* (2018) found that fertility care medical providers exhibited a bias toward patients with certain marital statuses, interfering with the approach used to collect patient information and recommended management, and ultimately affecting the quality of care (Sieverding *et al.* 2018). This bias may be seen in engineering design as a designer bias toward the intended end-user. Designers may have preconceived notions when collecting information on the intended user directly or indirectly, affecting the interpretation of the information collected as well as their perceived design solution. In addition to designers exhibiting bias because of the end-users' demographic status, designers may exhibit bias because of the end-users' race (Laidley *et al.* 2019).

Laidley *et al.* (2019) found that providers' racial bias influences their diagnosis of the patient (Laidley *et al.* 2019). Despite patients being siblings or having similar backgrounds, their skin tone was found to be a predictor of hypertension, with darker skin tone patients having a greater likelihood of being diagnosed with hypertension (Laidley *et al.* 2019). While the intended users in engineering design efforts usually have a shared aspect that groups them as the target customers, projects with racial differences among target users may shine a light on any racial biases held by designers. For example, designers may be attempting to provide a design solution to end-users of a community or organization with similar racial identities as their community. However, if these designers were attempting to provide the same design solution to a community or organization of end-users with

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racial identities that were vastly different from their community, would their approaches change? When designers interview the end-users or use techniques to uncover end-users' needs, there may be a bias that the designer holds that drives how the needs and expectations of the end-user are interpreted, their understanding of the problem and potentially the solution the designer suggests.

In the field of medicine, racial bias refers to reoccurring bias that negatively impacts the provider's interpretation of the patient's needs as well as the prescribed care (Hoffman *et al.* 2016; Plews-Ogan *et al.* 2020a). One very important example is that racial bias exhibited by medical providers has caused these providers to inaccurately assess the patient's level of pain (Hoffman *et al.* 2016). Racial bias plays a role in the interpretation of information as well as the synthesis of this information. In all stages of engineering design, but particularly in the *establishing needs phase*, racial bias impacts how the designers assess information shared by the intended user or information collected from the intended user and the design space can lead to the development of design solutions that fail. Being knowledgeable and aware of the racial bias by the designer that exists in engineering design can shine a light on how racial bias influences the first stage of the design process, which is a crucial design stage.

Another cognitive bias that can occur in the first stage of the engineering design process is utilization bias. Aberegg *et al.* (2006) identified that physicians demonstrate a bias leading them to forgo new beneficial information because of their need to not abandon their current practices even if their practices are not as beneficial (Aberegg *et al.* 2006). Though the design process is iterative, and designers gather new information throughout the design process, a bias like this can be harmful if exhibited in the early stage of gathering information and establishing the needs. In design, this may be expressed as a hindrance to designers when learning new methods to collect information or new approaches to evaluating information, or even when discovering new areas to collect information that can benefit their understanding of the end-user, the needs and project scope. It is important to understand if this bias exists among designers, how it is expressed and what effects it has on a successful design.

Two biases that exist in medical practice that may surface in the *analysis of task* phase are hindsight bias and weight bias (Persky & Eccleston 2010; Arkes 2013). Hindsight bias is the tendency to exaggerate the extent to which a past event could have been predicted (Arkes 2013; Saposnik *et al.* 2016). Arkes' (2013) literature review on the consequences of hindsight bias in medical decision-making found that hindsight bias affects learning and also leads to overconfidence when practicing medicine, which can result in malpractice (Arkes 2013). Medical decision-making and the *analysis of task* phase have several paralleling tasks. Hindsight bias and overconfidence in the *analysis of task* phase can lead to the designer's misinterpretation of the design problem and poor execution of design. Interpersonal biases may also influence medical decision-making. Persky and Eccleston (2010) found that physician recommendations differed based on the weight of the patient, suggesting that physicians demonstrate a weight bias (Persky & Eccleston 2010). Though the weight of a patient is assumed to be correlated to a person's health in the medical field, in design, weight or any visual appearance of the target user may impede the designer's decision-making. Designers may unconsciously exhibit an interpersonal bias toward their end-users based on the end-user's appearance or specific features, essentially an appearance or ability bias. This bias

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may be noted in the questions used to solicit information for the design project as well as in how the designer interprets that information. The bias may also show up when developing a product based on biased data sets such as weight and height data of a population (Nordqvist 2022). Weight is an important factor to consider when developing an ergonomic change, but if BMI tables are used as a standard to determine chair limits and constraints based on user weight, it will result in a biased design solution because BMI tables are inherently biased. An interpersonal bias that stems from someone's appearance can hinder the execution of the *analysis of task* phase if the designer is not aware that they hold such bias. This bias prevents the designer from understanding the design space or user needs fully.

The last four design phases are the *conceptual design phase*, *embodiment design phase*, *detailed design phase* and *implementation design phase.* All four phases have different objectives, but each phase shares similar tasks such as ideation, evaluation, selection, documentation, analysis and other cognitive tasks. One bias that occurs in medical design, testing, regulation and product use that may also occur in engineering design is gender bias. Hutchison (2019) found that there was a gender bias in the design and testing of hip implants due to the consideration and use of only male bodies and male-centered kinesiology (Hutchison 2019). The gender-biased hip implant design led to increased implant failures for female patients (Hutchison 2019). This bias directly relates to engineering design in practice because medical practitioners participated in designing the hip implant. In engineering design, gender bias may unknowingly occur if the metrics used to evaluate, test and demonstrate designs only use male participants. It is important to take into account the different gender demographics of the indented users when designing, to minimize design failure. Gender bias may be seen in the metrics used to evaluate the performance and functions of the design solution. Taking into account any gender biases in the final design stages can ensure the functionality of the final design solution for all the intended users.

In addition to design, testing and implementation, gender bias can also inform the selection of design concepts. Stålnacke *et al.*'s (2015) study identified that males had a significantly higher chance of being prescribed physiotherapy and radiological examination than female patients when presenting with chronic musculoskeletal pain (Stålnacke *et al.* 2015). This task is similar to the designer collecting information and selecting the best concept for the intended user or customer. Designers need to be aware of any gender bias or other interpersonal bias that exists when selecting concepts. One way designers can explore if a gender bias exists in this regard is to assess past projects for any trends that may suggest a gender bias.

Another bias that can influence selection or decision-making in the design process is racial bias. Green *et al.*'s (2007) study on the decision to treat patients found that physicians' implicit racial bias plays a significant role in the likelihood of not treating black patients (Green *et al.* 2007). This implicit bias may show up in engineering design unknowingly, especially when designing for users of different racial backgrounds which often occurs in humanitarian design or global development (Avgerou 2010). Engineering design is primarily conducted by white males, so there is a possibility that design thinking and decision-making may be biased when designers are designing with or designing for people of marginalized racial groups.

Medical research suggests confirmation bias may exist in these design stages (Mendel *et al.* 2011). Confirmation bias is the tendency to confirm a favored

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hypothesis (Tschan *et al.* 2009; Elston 2020; Nelius *et al.* 2020). Mendel *et al.* (2011) found that psychiatrists and medical students exhibited confirmation bias in their information search leading to diagnostic inaccuracies (Mendel *et al.* 2011). This situation in medicine is similar to the *establishing the needs phase* as well as the *conception selection phase* in engineering design. Confirmation bias in a designer may impact the information the designer searches trickling down to the methods used to develop and implement the design solutions. Confirmation bias may also influence the designer's ability to change their selection, decision or understanding, all being important actions throughout the design process.

In the final design phase, the *implementation* phase, the final design solution is transferred to the intended user by producing the product to scale, commercialization and mass production if needed. Documentation associated with the final design is also developed as a supplemental resource for users as well as other designers. Phillips, Wassersug, & McLeod (2012) study identified that documentation bias in supplemental pharmaceutical literature was linked to patients being less informed on drug side effects (Phillips et al. 2012). Some of the drivers for this documentation bias were due to the funding sources for the work. Documentation bias can unknowingly occur in engineering design as funding sources or stakeholders may unintentionally limit the information included in the final documentation. This bias can systematically influence what information is conveyed, available or made explicit to the end-user and other designers. Potential conflicts of interest may exist and unknowingly bias the content in the resulting documentation or supporting literature.

Though the design process can be divided into six different phases, most tasks are not exclusive to a single design phase. For example, decision-making, selection and even interviewing can occur in multiple phases of the design process. Biases that occur during medical decision-making are biases that can occur in all phases of the engineering design process. Hershberger *et al.* (1996) investigated cognitive bias in medical decision-making and found that both physicians and medical students demonstrate cognitive bias, but physicians were less susceptible (Hershberger *et al.* 1996). Student and professional designers may also exhibit cognitive bias in design decision-making. Decision-making tasks in design include selection, synthesis, evaluation, production, specification and many additional tasks that require design thinking. It is important to understand if cognitive bias plays a role in these tasks as it does in the field of medicine. It is also important to understand the variance of cognitive bias based on experience level or other designer traits.

Elston (2020) provided a review of cognitive bias, specifically confirmation bias, in medical decision-making (Elston 2020). Confirmation bias in the medical context is the tendency to give greater weight to data that supports a preliminary diagnosis while neglecting contradictory evidence (Elston 2020). This bias may occur in all stages of the design process. When collecting project or end-user information in engineering design, a confirmation bias may impede the designer's judgment if they are refusing to collect any information that may not support their findings. This may also occur with concept selection or even evaluation and synthesis of new information regarding conceptual design. The designer may disregard any information that suggests that the selected concept is not the best solution or fail to even consider such information due to a confirmation bias. Age plays a role in exhibiting confirmation bias, with older individuals being more

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likely to exhibit this bias. It is important to understand where confirmation bias is seen in design, its impacts, as well as the variance among designers based on experience as well as age, gender and race.

Saposnik *et al.*'s (2016) systematic review of the cognitive bias research in medical decision-making highlighted common cognitive biases that occur during management, treatment, diagnosis and/or prognosis (Saposnik *et al.* 2016). These biases include *anchoring*, *availability bias*, *blind obedience*, *commission bias*, *confirmation bias*, *diagnostic bias/premature closing*, *framing effect*, *omission bias*, *overconfidence*, *tolerance to risk* and *satisfying bias* (Saposnik *et al.* 2016). Though these biases occur and were studied in medical scenarios, they may also occur in engineering design scenarios. Management refers to how tasks within the scope are handled and regarded and is directly comparable to the management of tasks throughout the engineering design process. How is information handled? How is work within design teams distributed and executed? All these are ways where bias in the management of the design process can come into play. Management can be influenced by outcome bias, framing effect, anchoring or confirmation bias. It is important to understand this concept in the management of and within design projects. Medical decision-making, such as treatment and diagnosis, can be extrapolated to various design stages. Diagnosis is the interpretation of information to determine the presence or absence and quality of a disease in a patient. In engineering design, this can be compared to data interpretation from the end-user, in the early stages or prototype testing results and feedback from the final design stages. Overconfidence, outcome bias, anchoring or confirmation bias, and information bias have all been described in medical diagnosis, and may potentially occur in similar engineering design cognitive tasks. Treatment is the action that follows diagnosis. The emphasis is how the medical professional decides to provide a solution for their diagnosis. This may mimic the engineering design route the designer selects to use in the early design stages or even the approach used to produce and implement the final design. Framing effect, feedback bias and outcome biases can impact treatment in medical decision-making, so it likely impacts similar tasks in engineering design. Prognosis is the medical decision-making task of predicting the likelihood of a certain outcome of a disease or ailment. Though not as evident, prognosis is comparable to designers predicting the success or feasibility of a concept based on knowledge or with the use of tools to aid design. Simply, prognosis is the action of predicting an outcome. Though there are many design tools to assist in the design process and provide indicators that help make decisions, often design progresses to the next stages because of a designer's prediction of a solution or concept's success. If not successful, the designers investigate the problem and implement changes accordingly. The iterative nature of the design process partially relies on the prediction of the designers. Though tools and external resources have been developed to mitigate the human error of prediction, it is important to understand how cognitive bias in prediction shows up in engineering design.

Biases influencing decision-making not only are exhibited by individuals but can also be demonstrated by teams (Tschan *et al.* 2009; Helzer *et al.* 2020). Tschan *et al.*'s (2009) study suggests that confirmation bias exists in collaborative diagnosis and explicit reasoning within medical teams occurred more in groups that made the correct diagnosis (Tschan *et al.* 2009). Collaborative diagnosis in medicine parallels team ideation and concept selection in engineering design. Confirmation

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bias may exist in collaborative ideation or concept selection if design teams are not explicitly stating their reasoning, potentially leading to design solutions that fail. Bias in collaborative teams can also stem from team members' gender bias. Helzer *et al.*'s (2020) study highlighted that participants relied more on treatment advice delivered by a male physician versus a female physician (Helzer *et al.* 2020). It was also demonstrated that participants' reliance on the advice from female physicians increased based on the physician's experience, and this was not the case for male physicians (Helzer *et al.* 2020). This gender bias may occur when team members contribute information and even when instructors or managers offer advice to design teams. Designers may have a bias that prevents them from accepting helpful information due to the gender of the person providing the information. It may also be worth investigating if the experience of the person providing information influences how designers accept and use the information.

Research on bias in the medical field shows that medical providers can demonstrate bias, but some work also suggests the patient can exhibit bias. Levy and Hershey (2008) study explored patient bias and found that in close-call medical decisions, patients may exhibit value-induced bias (Levy & Hershey 2008). Value-induced bias is when someone distorts relevant probabilities to justify decisions, ultimately wishful thinking (Levy & Hershey 2008). Though in engineering design, most projects are not risky close calls like in some medical scenarios, end-users may exhibit this bias when tasked with decision-making when interpreting information conveyed by the stakeholder. The motivation to justify one's decision and preference may lead people to distort their perception of relevant possibilities. Levy's findings suggest that it is important to investigate the bias not only among the designers but also among the end-users. Research on bias in the practice of medicine highlights potential biases when executing engineering design that has not been investigated.

Bias research in engineering design has primarily explored biases that impact the practice or execution of design (Stacey *et al.* 1996; Toh *et al.* 2016; Nelius *et al.* 2020). Stacey *et al.* (1996) explored design tool bias in concept selection with the implementation of a design tool that mitigates and utilizes design tool bias to aid in concept selection (Stacey *et al.* 1996). This study highlights that design tools can be biased but that also bias can be beneficial to design outcomes. Toh *et al.* (2016) explored the variance of ownership bias in concept selection based on the designer's gender (Toh *et al.* 2016). Though gender bias was not explored, Toh found that male designers are more likely to demonstrate ownership bias than female designers (Toh *et al.* 2016).

5.2.3. Comparing medical research & engineering design research

One final domain of engineering design where bias may show up is in the process of engineering design research. Many aspects of engineering design are investigated in engineering design research such as designer protocols, effects of design solutions, tools that aid design, patterns in the design process, creativity and ideation, design thinking, and even documentation during the design process(Cardella, Atman, & Adams 2006; Maier & Fadel 2009; Caldwell 2011; Linsey *et al.* 2011; Van Bossuyt & Dean 2016; Kannengiesser & Gero 2017). As previously mentioned, Hutchison (2019) identified a gender bias in the design, testing, regulation and use of hip replacement (Hutchison 2019). Though this is considered a bias in design

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practice, it also highlights a bias that may exist in engineering design research because of the research that goes into product design. Research of design solutions consists of the development, testing and implementation of design solutions (Paleta, Pina, & Santos Silva 2014; Pinto *et al.* 2016). If a gender bias exists within these stages, developing and testing with a specific user in mind can lead to failed design solutions such as the hip replacement in Hutchison's case. This lack of inclusion highlights another bias that can show up in design research: participation bias.

Participation bias is when the participants of clinical trials fail to reflect the demographics of the patient populations (Murthy, Krumholz, & Gross 2004). Murthy *et al.* (2004) found that elderly and racially and gender-minoritized groups were less likely to enroll in cooperative group cancer trials than white participants, men and younger patients (Murthy *et al.* 2004). Though clinical trial studies differ from engineering design studies, a participation bias can be a factor in design research. Many engineering design studies are conducted at the institutional level, using undergraduate or graduate-level engineers as participants in those studies. The demographics of students enrolled in these engineering departments need to be considered to understand if a participation bias occurs. Most students enrolled in these engineering departments are white, male students, thus enabling the researcher to only collect data on design thinking that reflects the perspectives of younger white males (Roy 2019, 2020). It is important to understand how participation in clinical studies plays a role in biasing the data we used to understand design. Race and age-based disparities in medical research participation may be the result of social and economic disparities or other systematic factors such as racism; however, one's race is not a health risk factor. In design, particularly design research, race and sex disparities may influence design outcomes as these factors may influence decision-making in the design context (Helzer *et al.* 2020).

Another research bias that occurs in the medical field is reporting bias. Reporting bias refers to any bias that impedes what and how research findings are reported and published (McGauran *et al.* 2010). Some examples of reporting bias include publication bias, time-lag bias, multiple publication bias, location bias, citation bias, language bias and outcome reporting bias (McGauran *et al.* 2010). McGauran *et al.*'s (2010) review of reporting bias in medical research identified that many manufacturers and regulatory agencies withheld study data or attempted to suppress publications (McGauran *et al.* 2010). McGauran also found that reporting bias oftentimes revolved around the overestimation of efficacy and the underestimation of safety risks of interventions (McGauran *et al.* 2010). This study highlights how the nature and direction of the results can bias how the findings are reported. Reporting bias may occur in design research if the results go in a certain direction. Oftentimes, failed design efforts are not reported, which highlights a reporting bias in unsupportive findings. It may be beneficial to highlight how often studies go unreported because of the nature of the results. In addition to no reporting based on the nature of the results, reporting bias may also inform how research is documented. Researchers may oversell findings or withhold findings to achieve publication. This is an important phenomenon because reporting and publishing research findings are the primary way research is shared within the design community. Publishing is important for designers to understand what research is being conducted in the field but is also important for the expansion of engineering design as a field.

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Delgado-Rodríguez and Llorca (2004) reviewed the bias that impacts research in the medical field, identifying an extensive list of biases that influence medical research (Delgado-Rodríguez & Llorca 2004). These biases and the biases mentioned previously can be explored in engineering design by investigating the presence in the research pipeline. For the context of this study, the research pipeline refers to the funding, stakeholders, researchers, participants, data sets, tools, conferences, publications and other entities involved. Exploring these biases in these spaces will begin to close the gap in bias research in engineering design research.

6. Conclusion

Although the fields of medicine and engineering design have numerous similarities, the understanding of the role of bias in engineering design tasks and events is not as well understood. Bias research in the medical field highlights many potential opportunities for parallel bias research in engineering design. Bias may occur during end-user interviews, ideation, brainstorming, concept selection, decision-making or admissions, and even in funded conferences and educational courses. A summary of the comparison of actions and events where bias has been investigated in the fields of medicine and engineering design is depicted in Figure 4.

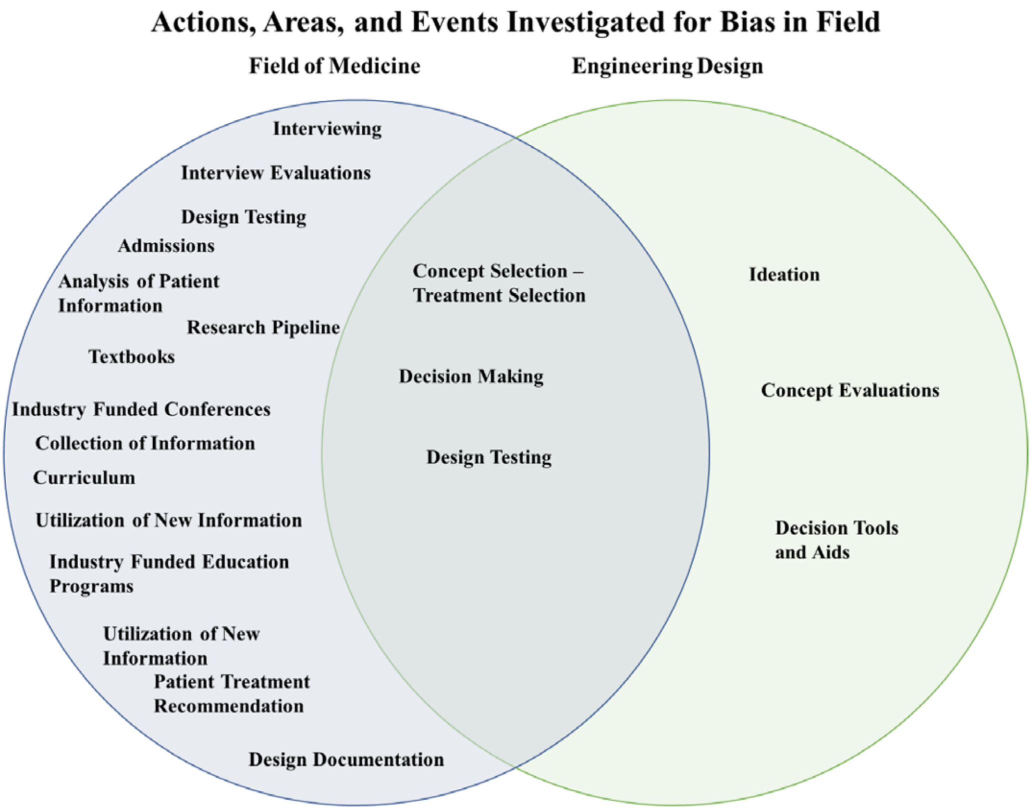

Figure 4. Comparison of actions, areas and events investigated for bias in the fields of engineering design and medicine.

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Using the context identified for bias in the medical field creates avenues for bias research in engineering design. In addition to identifying potential bias and engineering design, findings also identified potential sources for bias in engineering design to be investigated. It is important to understand where and what bias exists in engineering design, but it is also important to understand the potential causes for bias in engineering design. Listed below are the potential sources of bias based on the findings from the review of bias in the medical field.

6.1. Potential sources for bias in engineering design education

In the scope of this review, engineering design education encompasses the tasks involved to receive and provide engineering design education. This includes events such as the admission process into an engineering program that teaches design as well as events involved directly in engineering design instruction. Based on bias known in medical education, there are many scenarios in engineering design education where bias is having a potential impact. Starting with the admissions process, bias may occur during interviews for admission into engineering programs. In addition to the admissions process, bias may also influence the material and resources used in engineering design education, including textbooks and course curriculums. The content in the materials may contain racial and gender bias as seen in the example stated previously with medical textbooks (Benoit *et al.* 2020). White bodies and features were often used when discussing normal and healthy bodies in medical training unknowingly biasing medical students when they practice on patients that were not white. In addition to the content of course materials, the selection of those materials may be impacted by funding bias and/or information bias. The latter may also stem from educational partnerships, which have some benefits but still bias the curriculum. It is therefore important to take note of the potential impact of educational partnerships that fund the curriculum and/or filter the curriculum provided. The potential sources of bias in engineering design education may therefore be summarized as follows:

- ***Leniency bias***, ***racial bias*** and ***gender bias*** may impact admission into engineering programs that teach design programs and engineering design programs.
- ***Racial*** and ***gender bias*** may show up in engineering design textbooks and course materials. Based on findings highlighting the presence of bias in medical textbooks.
- ***Funding*** and ***information bias*** may show up in the curriculum used in engineering design education programs and be a result of educational funding and partnerships.

6.2. Potential sources for bias in engineering design in practice

Engineering design is in practice a variety of processes and tasks, including but not limited to understanding the user's needs, collecting information and transferring that information into the development of design solutions that meet the user's needs. Bias may be introduced in each of these stages. For instance, during customer interviews, designers may exhibit racial bias, leniency bias, weight bias and appearance bias. Bias can also influence cognitive tasks in engineering design such as collaborative decision-making. Cognitive biases may also influence the surveys and questionnaires developed by designers to collect user information.

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In addition to the tools used to collect user data, the data sets themselves may be biased as well, exuding racial, gender and information bias. Similar to bias in engineering design education, funding bias, information bias and outcome bias may stem from the influence of project funding and stakeholders. The potential sources of bias in engineering design practice may therefore be summarized as follows:

- ***Racial bias***, ***leniency bias*** and ***appearance bias*** may potentially influence the collection of user needs, particularly in customer interviews.
- ***Cognitive bias*** and ***interpersonal bias*** may show up during decision-making.
- ***Cognitive bias*** may influence survey and questionnaire development for customer data.
- ***Racial bias*** and ***gender bias*** may have biased the data available in data sets if the tools used to collect the data and the designers are exhibiting this bias.
- ***Information bias***, ***outcome bias*** and ***funding bias*** may stem from project stakeholders, funders and outlets for research.

6.3. Potential sources for bias engineering design research

Research in engineering design involves a range of tasks used to study all aspects and parts that make up engineering design. Like the biases that may occur in engineering design education and in practice, bias in design research may stem from both the design researchers and the stakeholders. Information bias, outcome bias and funding bias may also play a role in engineering design research and outcomes. Engineering design research can be viewed almost as a pipeline, from research funding and participation to research publications. Research on bias in medical research suggests there may be bias in engineering design research due to the similar contextual factors between engineering design research and medical research. The potential sources of bias in engineering design research may therefore be summarized as follows:

- ***Cognitive biases*** and ***interpersonal biases*** among researchers may lead to biased research.
- ***Biased*** data sets can influence the research outcomes.
- ***Information bias*** can result from limitations and representations at conferences can bias the work in the field of engineering design. Also limiting the methods and tools used in engineering design research.
- ***Publication bias*** from publication entities may influence what information can and cannot be published.
- ***Participation bias*** caused by a lack of diversity in the research participant population can bias research outcomes. A lack of diverse target end-users or customers can also bias the protocols that are established in engineering design.

7. Next steps for bias in engineering design

It is important to explore the various sources of bias to begin to understand and mitigate it. Research in the medical field has extensively identified sources of bias as well as methods for studying bias, including both qualitative and quantitative modalities. In this work, we turned to the field of medicine as an analog for engineering design, and through this comparison identified potential sources of

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bias in engineering design itself. Identifying the bias in engineering design can help understand the impact of bias on design education, projects and research. It is only through understanding these sources and influences that future work can begin to explore strategies for mitigation.

The three domains studied in this work – education, research and practice – act as three future research areas for bias in engineering design. In large part, this work has introduced hypotheses for where bias may occur in engineering design. Therefore, future work needs to investigate if the identified biases truly exist in the identified scenarios. In addition to the scenarios identified here, researchers should also investigate other scenarios in engineering design that may not have explicit parallels in medicine but are still crucial to engineering design. To do so, future work should begin investigating the aspects of engineering design that are known as vital for effective and successful engineering design. For example, bias is known to influence interpersonal relationships in medicine and interpersonal relationships are crucial to executing engineering design. Future work can explore if and how bias affects interpersonal relationships between designers and end-users or within design teams. Effective characteristics in education, in research and when practicing design can shine a light on areas to investigate the influence of bias. Future work should identify not only the bias that exists but also ways to mitigate or utilize the bias for the benefit of the design and the intended users. This can be done by exploring existing debiasing approaches in and out of the field of engineering design as well as the opportunities to expand the debiasing approaches. An understanding of bias that exists and ways to mitigate bias enables designers to understand bias and its impacts holistically.

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Appendix

Table 2. Publication details and data (Aberegg *et al.* 2006; Arkes 2013; Benoit *et al.* 2020; Capers *et al.* 2017; Dijkstra *et al.* 2008; Elston 2020; Green *et al.* 2007; Griffin & Wilson 2010; Hall *et al.* 2015; Helzer *et al.* 2020; Hershberger *et al.* 1996; Hoffman *et al.* 2016; Hutchison 2019; Laidley *et al.* 2019; Levy & Hershey 2008; McGauran *et al.* 2010; Mendel *et al.* 2011; Murthy *et al.* 2004; Persky & Eccleston 2010; Phillips *et al.* 2012; Pinzur 2020; Plews-Ogan *et al.* 2020b, 2020a; Saposnik *et al.* 2016; Schofferman 2015; Sieverding *et al.* 2018; Stålnacke *et al.* 2015; Stone & Moskowitz 2011; Tripepi *et al.* 2010; Tschan *et al.* 2009).

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
Academic Medicine	Acting Wisely: Eliminating Negative Bias in Medical Education—Part 1: The Fundamentals	Plews-Ogan, M. (2020)	Multiple Biases in Medical Education	Education	Medical educators	Medical Students	Provide a "wisdom" framework for understanding and mitigating bias in medical education	Cognitive and social psychology science on bias and mitigating negative effects of bias in medical teaching and mentoring.	Literature Review
Academic Medicine	Acting Wisely: Eliminating Negative Bias in Medical Education—Part 2: How Can We Do Better?	Plews-Ogan, M. (2020)	Multiple Biases in Medical Education	Education	Medical educators	Medical Students	Describe how those skills can be applied to create the interpersonal, structural, and cultural elements supportive of a culture of respect and inclusion in medical education.	Actions medical educators can take to do better to mitigate bias	Literature Review
Academic Medicine	Toward a Bias-Free and Inclusive Medical Curriculum:	Benoit, L. (2020)	Multiple Biases in Medical Education	Education	Curriculum	Information Shared	Bias-influenced remarks made when training medical students	The bias-free inclusive medical curriculum	Tool Development and Implementation

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
	Development and Implementation of Student-Initiated Guidelines and Monitoring Mechanisms at One Institution								
American Orthopedic Foot & Ankle Society	Bias in Medical Education	Pinzur, M. (2020)	Bias in Medical Education	Education	Curriculum	Information Shared	Identifying subtle bias that occurred at an industry-sponsored educational program	Educational programs' presentation of certain data	"Call to action"
Academic Medicine	Implicit Racial Bias in Medical School Admissions	Capers IV, Q. (2017)	Racial Bias	Education	Admission Committee Members	Medical School Applicant	**Acceptance/ Admission** - accepting applicants to medical school	Existence of implicit racial bias in medical school admissions committees.	Descriptive
Pain Medicine	Industry-Funded Continuing Medical Education: The Potential for Bias	Schofferman, J. (2015)	Education Bias	Education	Curriculum	Information Shared	Industry-funded Continuing Medical Education	Potential bias in industry-funded medical education	Journal Article Forum
Medical Journal of Australia	Interviewer bias in medical student selection	Griffin, B. (2010)	Interviewer Bias - Leniency Bias	Education	Interviewer	Interviewee	**Evaluation** - of the MMI for medical school	**Interviews** - Interviewer personality, sex, or being of the same sex as the interviewee, and	Descriptive

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
								training account for variance between interviewers' ratings in a medical student selection interview.	
Medical Education	Gender bias in medical textbooks: examples from coronary heart disease, depression, alcohol abuse and pharmacology	Dijkstra, A. (2008)	Gender Bias	Education	Textbook Content	Textbook User knowledge?	**Resources/Data Set**	**Resource/Data Set** - whether current nationally and internationally accepted medical textbooks reflect the state of the art on gender-specific knowledge	Descriptive
The International Journal of Clinical Practice	Systemic bias in the medical literature on androgen deprivation therapy and its implication to clinical practice	Phillips, J. L. (2012)	Documentation Bias	Education & Practice	Literature/ Author of the LIterature	Pharmaceutical user	Pharmaceutical Literature documentation of side effects and alternatives	If pharmaceutical literature provided information on the side effects of LHRH agonists as well as the alternatives to LHRH for ADT	Descriptive - Qualitative Analysis
Advances in Health Sciences Education	Understanding and Addressing Cognitive Bias in Medical Education	Hershberger, P. (1996)	Cognitive bias in decision-making	Education and Practice	Medical student/ practicing physician	Decision	Cognitive bias in decision-making by medical students and physicians	Extent to which medical students and practicing physicians avoid	case study and experimental study

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
								cognitive bias in medical decision-making; extent of variance of cognitive bias with medical specialty; awareness of cognitive bias in medical decision-making can be taught	
Medical Decision-making	Failure to Adopt Beneficial Therapies Caused by Bias in Medical Evidence Evaluation	Aberegg, S. (2006)		Practice	Physician	Physician Practices	**Utilization** of information and **Decision-making** from that information	**Utilization** - Respondents' willingness to apply the results of the hypothetical trial to patient care	Experiment
Journal of the American Academy of Dermatology,	Confirmation Bias in Medical Decision-Making	Elston, D. (2020)	Confirmaition Bias Achoring Bias	Practice	Physician	Physician Practices	Medical Decision-making	Medical decision-making	Letter to the Editor
BMC Medical Informative and Decision-making	Cognitive Biases associated with medical decisions: a systematic review	Saposnik, G. (2016)	Various Types	Practice	Physician	Physician Decisions	Reviewed literature that reported evidence on the relationship between cognitive biases affecting physicians and medical decisions	1) To identify the most common cognitive biases by subjecting physicians to real-world situations or case vignettes, 2) to evaluate the influence of	Systematic Literature Review

Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
								cognitive biases on diagnostic accuracy and medical errors in management or treatment, 3) to determine which cognitive biases have the greatest impact on patient outcomes, and 4) to identify literature gaps in this specific area to guide future research	
Decision Psychology and Judgement	Value-Induced Bias in Medical Decision-making	Levy, A. (2008)	Value-Induced Bias	Practice	Patient	Desired Treatment Choice	Desire treatment based on the information provided	Medical decision-making by patient	Experiment
International Journal of Obesity	Medical Student Bias and Case Recommendations for an Obese vs Non- Obese Virtual Patient	Persky, S. (2010)	Weight Bias	Practice	Medical Student (Physician)	Patient	**Recommendations** for patient care	Care recommendations provided by the medical students	Experiment
Academic Medicine	Gender Bias in Collaborative Medical Decision-	Helzer, E. (2020)	Gender Bias	Practice	Team Member	Treatment decision	**Reliance on Information** based on gender	**Collaborative (Team) Decision-making**	Exploratory

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
	making: Emergent Evidence								
Small Group Research	Explicit Reasoning, Confirmation Bias, and Illusory Transactive Memory: A Simulation Study of Groups	Tschan, F. (2009)		Practice	Team Member	Diagnosis	Collaborative Reasoning; **Group Information collection, Group Decision-making; Talking to the Room**	**Collaborative (Team) Reasoning**	
Proceedings of the National Academy of Sciences of the United States of America (PNAS)	Racial Bias in pain assessment and treatment recommendations, and false beliefs about biological difference between blacks and whites	Hoffman, K. (2016)	Racial Bias	Practice	White people; White medical students	Patient	**Assessment** of pain; **treatment** of pain	**Assessment** - Perception of patient pain and Belief of racial stereotypes; **Treatment** - perception of pain, racial beliefs and recommended treatment	Experiment
International Perspectives on Sexual and Reproductive Health	Bias in Contraceptive Provision to Young Women Among Private Health Care Providers in South West Nigeria	Sieverding, M. (2018)	Provider Bias	Practice	Provider/ Physician	Client	Physician–Patient **Interaction** and **Recommendations**	Designer–End-user interactions	Experimental/ Descriptive
Demography	New Evidence of Skin Color Bias and Health Outcomes Using Sibling	Laidley, T. (2019)	Racial Bias	Practice	Physician	Patient diagnosis	**Assessment** of patients being **diagnosed** with hypertension	Does skin tone bias exist in the **diagnosis** of hypertension?	Descriptive

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
	Difference Models: A Research Note								
Journal of General Internal Medicine	Implicitly Bias Among Physicians and its predictions of thrombolysis decisions for black and white patients	Green, A. (2007)	Racial Bias	Practice	Physician	Patient	**Recommendations** - Recommendations made for black and white patients with acute coronary syndromes	**Decision** - Decision to recommend treating thrombolysis	Experiment
Journal of Rehabilitation Medicine	Is There Gender Bias in Recommendations for Further Rehabilitation in Primary Care of Patients with Chronic Pain	Stålnacke, B. (2015)	Gender Bias	Practice	Interdisciplinary Teams	Patient	**Recommendations** for rehabilitation care	**Selection** - of rehabilitation treatment	Descriptive
Psychological Medicine	Confirmation bias: why psychiatrists stick to wrong preliminary diagnoses	Mendel, R. (2011)	Confirmation Bias	Practice	Psychiatrists and Students	Patient Diagnosis	**Determining Diagnosis** - the process of interpreting information for the diagnosis, searching for information for the diagnosis, and evaluating the initial diagnosis	**Selection** - selecting the perceived correct diagnosis	Experiment
Current Directions in	The Consequences of the Hindsight Bias	Arkes, H. (2013)	Hindsight Bias	Practice Education	Physician		Explores how hindsight bias		Literature Review

Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
Psychological Science	in Medical Decision-making					Patients & Physician Decisions	shows up in various forms of medical decision-making	Learning, overconfidence and malpractice	
Medical Education	Non-conscious bias in medical decision-making: what can be done to reduce it?	Stone, J. (2011)	Non-conscious Bias Implicit Bias	Practice Education	Physician	Patient	Medical Decision-making when providing health care services to members of stigmatized groups	Contemporary training in cultural competence	Literature Review
Trials	Reporting Bias in Medical Research - a narrative review	McGauran, M. (2010)	Reporting Bias (publication Bias and selective outcome reporting)	Research	Publisher; Manufacturer; author	Published Data	Results of clinical research	Reporting research; publication bias and selective outcome bias	Descriptive (Literature Review)
JAMA	Participation in Cancer Clinical Trials: Race-, Sex, and Age-based Disparities	Murthy, V. (2004)	Participation Bias	Research	Study Participants	Clinical Trial Data Sets	Participation in clinical trials sponsored by the national cancer institute	Participation in clinical trials	Descriptive
Hypatia	Gender Bias in Medical Implant Design and Use: A Type of Moral Aggregation Problem?	Hutchison, K. (2019)	Gender Bias	Research & Practice	Designer	design solutions and technologies	**Design, Testing, Regulation, and Use** of implants	Gender bias in the **design, testing, regulation** and **use** of implants	Descriptive (Literature Review)
	Implicit racial/ethnic bias among health	Hall, W. (2015)	Racial Bias	In Practice	Health Care Professionals			Medical professional care and outcomes	

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Table 2. Continued

Publication	Title	Author (Date)	Bias investigated	Education, research, and/or in practice	Bias agent	Bias recipient	Context	Event, action and/or task investigated	Study design
American Journal of Public Health	care professionals and its influence on health care outcomes: a systematic review					Patient and Health Care outcomes	Physician–Patient **Interaction** and **Recommendations**		Systematic Literature Review
Clinical Research	Selection Bias and Information in Clinical Research	Tripepi, G. (2010)	Selection Bias	Research	Researcher & Clinical Study	Research Publications & Data	Types of bias in data analysis of clinical research	Data analysis and presentation	Review