ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37373

Investigating a Socially Engaged Design Process Model

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Investigating a Socially Engaged Design Process Model for Engineering Education

Abstract

Educators can leverage a variety of process models to scaffold students from beginning designer practices to practices aligned with more experienced designers. The Center for Socially Engaged Design at the University of Michigan developed a Socially Engaged Design (SED) Process Model to explicitly emphasize important aspects of design that are often underemphasized or not included in commonly-used design process model visualizations, including, for example, designers embracing the limitations of their own perspective and acknowledging the power they hold, the benefits of integrating contextual considerations, and the use of prototypes throughout a design process rather than as single phase in a design process. To better understand the role of design process models, broadly, and the perceived value of process models that emphasize the importance of people and context in design work, specifically, we investigated upper-level mechanical engineering students' perceptions of this SED Process Model's visualization. Our findings from this initial exploratory study showed both variability and several consistent themes in participants' perceptions, for example, there were several interpretations of relationships between different aspects of the model, iteration in design was salient to all participants, and while this SED Process Model's visualization does have recommendations, several participants noted it does not specify exactly how to achieve those recommendations. Understanding engineering students' perceptions of this SED Process Model's visualization can help us (1) iterate on the process model's visualization and (2) better understand how to leverage multiple process model visualizations in engineering curricula.

Introduction

Design process models are valuable tools to support designers in their work. However, no single design process model can encompass everything a designer should do in every design situation. Leveraging multiple design process models allows students to recognize that there is no single way to design successfully, i.e., "*the*" design process does not exist. Design process models are often represented by their visual representations, although we acknowledge that design process models are often accompanied by additional text-based descriptions, for example [1]–[3]. When looking at collections of models (e.g., [4], [5]), many of these models' visualizations are missing aspects of design that have recently been highlighted as important in the design literature, and thus should be explicitly recognized as part of a design process. For example, designers should acknowledge the power they hold in design work [2], [6], design decisions benefit from investigation and incorporation of the context in which the design will be implemented [7], [8], and design outcomes advance from the use of prototyping throughout a design process rather than as single phase in a design process [9]–[11].

In general, engineering culture and education de-emphasizes—and students may struggle to attend to or face barriers in attending to—social complexity, including the role of people and context [12]–[18]. There are some design process model visualizations that refer to stakeholders, for example, by describing "Empathize" as a stage in design work (e.g., [2]). However, many process model visualizations do not explicitly attend to stakeholders or context (e.g., [1], [4]), although some models refer to the market, ergonomics, and economic criteria (e.g., [19, Fig. 4.3]) or communication (e.g., [4, p. 34]), which do relate to people. As a way to include the roles of people—both stakeholders and designers—and the context of design work, as well as emphasize aspects of design that are not often included in existing design process model visualizations, the Center for Socially Engaged Design at the University of Michigan developed a Socially Engaged Design (SED) Process Model that take a humanity-centered approach. We refer to this developed process model as "this" SED Process Model throughout this paper to highlight that the visual representation shared in Figure 1 and described in the background section is one of many possible representations of socially engaged design.

A humanity-centered design approach places emphasis on deep consideration and inclusion of stakeholders and context in design decision making. Further, when taking a humanity-centered approach, designers consider how their own identities shape design approaches and outcomes, constantly reflect and analyze on—and adjust—their role in a design process relative to the people and communities who have a stake in the project, and account for impacts on future generations. As a humanity-centered approach, socially engaged design thus foregrounds people and society (e.g., users, stakeholders, communities), context (e.g., environmental, political, economic, cultural), and designer positionality (relative to the problem, solution, and process) throughout design work [20]. This SED Process Model facilitates awareness by naming aspects of design that have been underemphasized in design broadly and recommends use of particular practices throughout a design process. The goal of socially engaged design within engineering is to equitably address complex societal challenges through collaborative, reciprocal relationships that build upon deep analyses of design context, positionalities, and technical knowledge.

While this SED Process Model highlights these important aspects of design work, there is limited research on how engineering student designers interpret design process model visualizations as well as how they might perceive the value of a model that attends to people, context, and designer positionality in design work. Further, as design process models are often represented by their visualizations, these visualizations serve as a proxy for the key aspects of the design processes that they represent. Studies have not considered what engineering student designers take as important based on what is included in visual representations of design process models. Thus, our research focused on a preliminary investigation of mechanical engineering students' perceptions of this SED Process Model's visualization. We conducted semi-structured interviews with upper-level undergraduate mechanical engineering students to investigate their perceptions of what aspects of design are emphasized in this SED Process Model's visualization and what aspects of design are missing from the visual representation of the process model, as well as parts of the visual representation that are confusing or unclear. Findings can guide SED Process Model visualization iterations, the development of instructional materials for how to use this SED model, and, more broadly, ways to use design process model visualizations within engineering education contexts.

Background

Several existing design philosophies have overlaps with a humanity-centered design approach. For example, user-centered design emphasizes ease of use for end-users [21], [22] and human-centered design recognizes the necessity of gathering information from people [23]. These design philosophies align with how a humanity-centered design approach places emphasis on deep consideration and inclusion of stakeholders in design decision making. As a humanity-centered approach, socially engaged design holds people, context, and designers' positionalities as important contributors throughout design work.

Furthermore, some existing design process model visualizations have aspects that are in alignment with socially engaged design, generally, as well as this Socially Engaged Design (SED) Process Model's visualization, specifically. For example, Stanford d.school's Equity-Centered Design Framework consists of six "modes" or stages presented linearly from notice, to Empathize, Define, Ideate, Prototype, Test, and Reflect [2]. From the visual representation alone, we see consideration of people explicit in the inclusion of "Empathize" and consideration of designers explicit in the inclusion of "Reflect." If you dig further into the text that describes the "Notice" stage, it is described as acknowledging "Power, Identity, Context" [2, p. 17]. However, with our focus on visual representations—as indicating the most important aspects of a design process—we aim to make consideration of context more explicit in this SED Process Model's visualization as designers may not always refer back to text descriptions.

As another example, the EPICS Design Process Model developed for the Engineering Projects in Community Service (EPICS) Program at Purdue University consists of seven phases presented in a circle starting with Project Identification at 12 o'clock and followed clockwise by Specification Development, Conceptual Design, Detailed Design, Delivery, Service/Maintenance, Redesign/Retirement with iteration arrows within each phase [24]. From the visual representation alone, we see consideration of people explicit with the inclusion of the word "Stakeholders" boxed-in within the center of the circle. Furthermore, consideration of users is explicit with the inclusion of "User Analysis", "User Training", and "Usability Testing." A deeper dive into the text description of this EPICS Design Process [25] reveals that understanding and describing the social context of community partner(s) is embedded with the "Project Identification" and "Specification Development" phases. Again, we aim to make consideration of context more explicit in this SED Process Model's visualization. Furthermore, the EPICS Design Process Model does not explicitly attend to designer positionality which is a foundational aspect of socially engaged design.

The visual representation of the design process model developed by the Center for Socially Engaged Design is shown in Figure 1. The model is intended to be both descriptive and prescriptive; descriptive models of design capture how design occurs in practice, while prescriptive design process models convey how design ought to occur, and some models have characteristics of both types [26], [27]. A descriptive design process can be as simple as a question mark connected to a dollar sign by a squiggly, backtracking arrow, such as what Tim Brennan used to explain how Apple Computer's Creative Services department worked [4, p. 10]. Descriptive models are useful for conveying important aspects of design processes such as how messy design can be or how a design process must ultimately converge. Prescriptive design process models explicitly name aspects of design that designers should attend to while designing. For example, French's [1, Fig. 1.1] model of a design process names four phases—analysis of problem, conceptual design, embodiment of schemes, and detailing—and includes feedback loops between three of these phases.

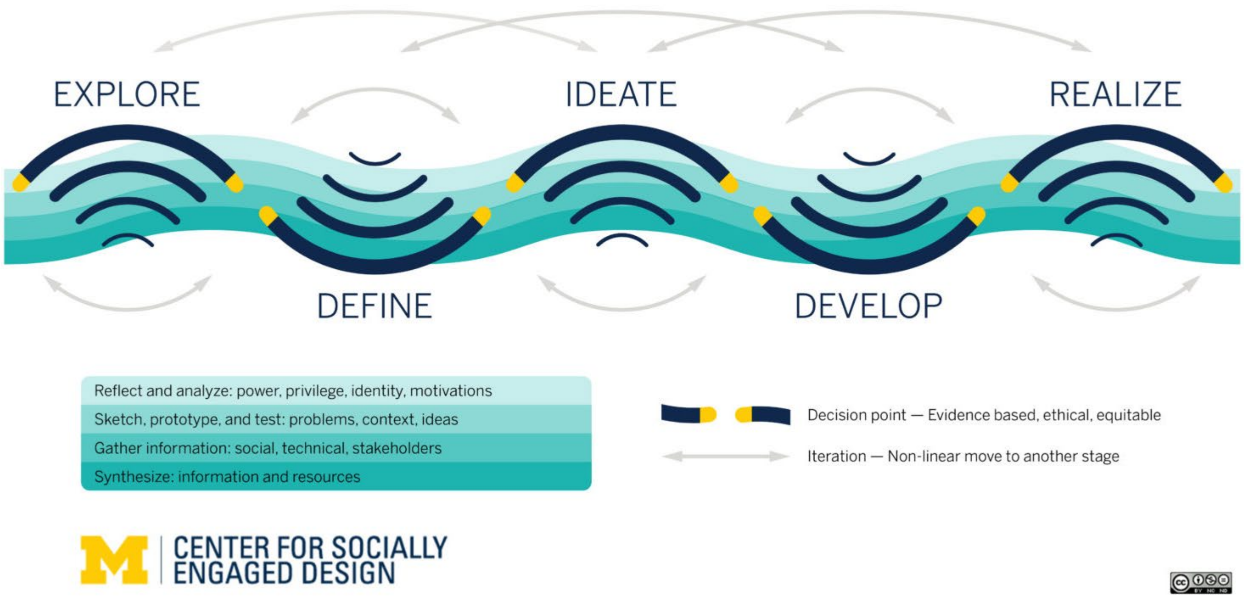

FIGURE 1 Socially Engaged Design Process Model [20]

By having both descriptive and prescriptive characteristics, this Socially Engaged Design Process Model conveys both what socially engaged design looks like in practice and suggests what socially engaged designers do. In the following paragraphs, we discuss important aspects of the SED Process Model and connect these aspects to existing literature, including literature compiled in an internal document synthesizing some key literature supporting the model [28]. This text-based description of this Socially Engaged Design Process Model is provided for the reader of this article and was not shared with research participants.

Five Stages. This Socially Engaged Design Process Model is organized into five stages: Explore, Define, Ideate, Develop and Realize. In each of these stages designers must leverage both divergent and convergent thinking, initially diverging but ultimately converging to a decision point the end of each stage. Both divergent and convergent thinking have important roles in supporting creativity in design and need to be balanced; both (1) divergent thinking without convergent thinking and (2) too much convergent thinking can cause problems [29].

In the Explore stage, designers search for and identify a problem area or further explore a given problem while beginning to build community partner relationships. The Explore stage includes gathering multiple types of information and conducting secondary research about, for example, how the problem has been addressed in the past, root causes of the problems, how the problem is situated in current socioeconomic conditions, what stakeholders have typically been left out of conversations, and how the problem impacts and interacts with the environment. Further, the Explore stage includes gathering information first-hand from different stakeholders in order to better understand those who affect or are affected by the problem. The inclusion of the Explore stage in this process model is aligned with several best practices from needs assessment literature, including gathering different types of information, interacting with multiple stakeholders, and engaging communities and/or community organizations as partners [30]. In addition, the Explore stage is supported by research that shows that gathering more information and a wide variety of information supports the quality of design outcomes [31] and that ties front-end design practices to the success of new products [32], [33]. Research has shown the importance of involving stakeholders in front-end design [34] and the positive impact stakeholder involvement has on the chances of developing products that not only work, but are appropriate [35], [36]. Furthermore, community-based and social change research has established the importance of understanding community histories [37] and the context of design researchers' associations with institutions or organizations [38], particularly with respect to how researchers engage with communities.

Information gathered during the Explore stage is synthesized in the Define stage of this SED Process Model into a new or refined problem statement, needs, requirements, and specifications that are all solution-neutral. Problem statements clarify what the problem is by providing contextual information, describing the goal, and communicating constraints [39], while needs statements—also sometimes written as "How Might We" questions [23], [40]—are concise statements that convey what changes would have to occur for the problem to be resolved [34], [39]. Requirements—often written in the language of the end-user—are the qualitative criteria for a desired solution [3], [41], while specifications are the translation of requirements to quantitative criteria that can be verified [41], [42]. Problem statements and needs statements are therefore focused on understanding what the problem is, while requirements and specifications are focused on understanding what would make a successful solution. The Define stage is focused on how the problem is described, with the goal to appropriately represent the "real" problem, as well as what a solution must accomplish—to facilitate later generation of practical and creative solution ideas. Defining what the problem is and the criteria for a successful solution is a critical step in any design process because if engineers design and create a solution that works, but it was not the right solution, i.e., it does not actually solve the problem, they have failed [43]. Additionally, the way the problem is framed impacts the types of solutions that are explored [39], [44], [45], and a problem framed too narrowly or inadequately hinders successful idea generation.

The Ideate stage uses the problem as it was structured during the Define stage to facilitate the generation of many concepts that could potentially address the defined problem. The Ideate stage does not end with the selection of a "best idea," but rather is complete when a variety of options are available for further development. Quantity and variety are two metrics used to evaluate the effectiveness of idea generation [46]. Quantity is often a goal in idea generation because research supports that generating more ideas improves chances of generating high quality and innovative ideas [46]–[53]. Variety, or how diverse a collection of ideas is, serves as an indicator of how well a design space has been explored and accounts for the fact that a high quantity of similar ideas does not constitute effective idea generation [46]. Research findings suggest that designers should begin ideation by working through the ideas that they already have [54]. After an initial round of generating ideas, a goal to produce a high quantity of ideas can push designers to engage in further ideation, now leveraging the many different tools, techniques, and methods for supporting concept generation, (e.g., [55]–[57]). Evaluations of variety—either quantitative (e.g., [46]) or qualitative (e.g., do solutions represent perspectives of a range of stakeholders?)—can help designers intentionally work against any biases they may have based on their own identity, power, privilege, and motivations as well as determine if they are ready to move from the Ideate stage to the Develop stage.

The Develop stage of this SED Process Model considers the collection of ideas generated relative to the problem, needs, requirements, and specification—all of which should acknowledge stakeholders and context—and considers ways that these ideas can be modified to best meet the goals of the work. This stage includes multiple rounds of iteration to evolve ideas to meet technical, social, and contextual criteria. These evolved ideas are analyzed to prompt further iteration and development, as well as to narrow down to developed ideas that seem most promising. Based on this analysis, some ideas are iterated on in a gradual process towards convergence on a single solution. Although, divergence may still occur during the Develop stage, for example, if feedback on an idea leads to the generation of several new ideas. The ultimate selection of a solution is supported by further refining several solutions based on testing, feedback from stakeholders, secondary research, and numerous support tools. Analysis, development, and selection tools and strategies include decision matrices—which may be weighted—[3], [42], usability testing [58], [59], six thinking hats [60], pros and cons [42], plusses, potentials and concerns (PPC) [61], concept combination tables [42] and quality function deployment [3]. This Develop stage aligns with aspects of the product development process described by Pahl et al. [19], where “Conceptual Design” and “Embodiment Design” involve iterative refinement and development of concepts and one, or a few, principle solutions, respectively.

The Realize stage of this SED Process Model is a purposely broad stage because the “realization” of a design outcome can mean many things. Sometimes the Realize stage consists of implementing a system, service, curriculum, or other intervention developed in the previous stage. The Realize stage may look like validating a physical product with users and other stakeholders. Or, the potential solution from the Develop stage may, for example, prompt designers and/or stakeholders to begin to understand the problem differently or shift priorities; these changes can necessitate revisiting previous stages in the process for more ideating, to redefine the problem, or perform further exploration, which is reflective of how problems and solutions co-evolve [62]. Other times the Realize stage is a moment where, upon reflecting on their own positionality, designers “realize” they are not the people who should be addressing a particular challenge, the most appropriate solution is outside of their skillset, or they can address a portion of a multi-faceted solution but will need to develop partnerships to implement the full solution. The inclusion of this Realize stage aligns with Norman’s and Stappers’ [63] suggestion that when tackling the challenges of complex sociotechnical systems, designers “must play an active role in implementation.” Both verification and validation—confirming the solution meets requirements and confirming the solution meets requirements for its intended use, respectively [64]—are common activities across engineering disciplines. For example, systems engineering [65], requirements engineering—described as a subset of systems engineering— [66, pp. 11–13], and production engineering [67]. In the context of this SED Process Model, validation of a physical product would necessitate stakeholder engagement.

Iteration. Progression through a design process and iteration connect the five stages to each other. The light gray arrows represent iteration within and between stages, including non-linear movements between stages, and indicate that a SED process should be iterative. While designers are generally moving from the Explore stage to the Realize stage, a SED process is not only a forward-moving process; at times designers will need to go back to previous stages or jump ahead to future stages. In contrast to the undercurrents, which are done throughout a design process, the iteration arrows overlay the design process to represent intentional decisions to engage in iteration. Design has been described as inevitably involving iteration [68]. The inclusion of iteration in this SED Process Model is aligned with the frequent occurrence of iteration in product development [69] and the prevalence of transitions among senior student engineering designers—relative to freshman [70]. When working on complex problems, unpredictable interactions are likely (e.g., [71]) —similar to ripple effects described below—and designers will usually discover new information and have new ideas as they understand a problem and potential solutions more.

Wave and Decision Points. The five stages sit along a thick dark blue line that takes on a wave shape meant to acknowledge that although designers are generally converging towards a solution, the process is always fluctuating and changing in its clarity, ease, and scope; the process is not necessarily straight or uniform. The wave representation aligns with Buchanan's [72, p. 15] understanding that "the actual sequence of design thinking and decision-making is not a simple linear process… the problems addressed by designers do not, in actual practice yield to any linear analysis and synthesis."

The wave shape is divided into five pieces where each piece has yellow end points. These breaks in the wave act as stop signs or decision points between the five stages. Before moving from one stage to another, designers are encouraged to take time to pause and reflect in order to make decisions that are evidence based, ethical, and equitable. Thus, socially engaged design recommends designers to be reflective practitioners—to look back at both their design process and current design outcomes at regular intervals [73]. Different decision points will require different kinds of reflection but generally designers may be asking themselves: Do I have enough information to move forward? What information is still missing? Is this meeting the needs of my stakeholders? What questions do I need answered? How can I get answers to those questions? Are there biases or assumptions that might be influencing my decisions? Am I prioritizing the development of a new technology over community outcomes? Given what I know, should others be brought into this process or lifted into a position with more decision-making power?

Krishnan and Ulrich's [74] literature review of product development highlights a variety of decisions within product development including: "What are the target values of the product attributes, including price?", "What technologies should be used for prototyping?", and "What will be the overall physical form and industrial design of the product?". The decision points within this SED Process Model encompass questions such as those just listed, but also aim to support equitable outcomes similar to "Equity Pauses" [75]. The term "Equity Pause"—utilized in the Equity-Centered Design Framework [2] and first coined by equityXdesign—refers to intentional stops after each design stage to reflect and ensure ideas do, and continue to, support the achievement of equity. Furthermore, such decision points serve as an opportunity to check if decision-making process are in alignment with best practices. For example, Harrington et al. [76] recommend leveraging existing community assets and emphasizing community metrics for success over the development of new technology to support equitable community-based participatory design.

Ripples. In each stage there are progressively shorter and thinner dark blue lines that are intended to evoke the image of ripples in water. The ripples serve as a reminder to consider ripple effects—unintended consequences of design decisions—and of the multiple levels of complexity within a design process. Walsh, Dong, and Turner [77] proposed a theory for unintended consequences in engineering design while highlighting "the necessity of minimizing unintended consequences, if engineering design aims to be responsible." Many complex natural and social systems consist of nonlinear relationships where changes in input cause disproportionate changes in out and thus make system prediction impossible [78]. The ripples in this SED Process Model acknowledge that the problems socially engaged design seeks to address have, by definition, the complexity of social systems.

Four Undercurrents. Behind the five stages there are four undercurrents presented as wavy lines that go from lighter shades of turquoise at the top to darker shades of turquoise at the bottom. While the five stages (Explore, Define, Ideate, Develop, and Realize) are foregrounded in this SED Process Model, these four undercurrents: Reflect and analyze; Sketch, prototype, and test; Gather information; and Synthesize, run through each of the five stages. The stages represent specific actions in specific parts of a design process, while the undercurrents represent the things that designers are doing throughout a design process, no matter what stage they are in. This SED Process Model does not fit perfectly within the classification scheme of stage vs. activity-based models as the scheme is described in [5], but does have parallels with "combined models". The five stages parallel the structure of a design process, while the undercurrents parallel the iterative activities that occur in every stage. Many activity-based models include analysis, synthesis, and evaluation [79], [80], which parallels, but are not fully aligned with, several of the undercurrents included in this SED Process Model.

The undercurrent, "Reflect and analyze: power, privilege, identity and motivations," is intended to highlight designers' understanding of their own experiences, identities, and positionality is a key part of the reflexive practice that characterizes the humanity-centered approach within socially engaged design. In alignment with researchers who conduct community-based participatory research (e.g., [37]), socially engaged design is concerned with how design takes place as much as, or even more than, particular design goals. In addition, given the importance of history and context [37], [38], designers should consider the unique history and context of each stakeholder engagement and actively integrate those reflections into their practice as way to build trust with stakeholders [76].

Several, non-exhaustive, examples of prompts for individual reflection include: What are my motivations for doing this work? Am I truly the best person to be undertaking this part of the work? What information or skills might I be lacking? In what ways might my own motivations be influencing the process? What identities and privileges do I bring to my work and are they different from the people involved? What does power look like in these spaces? How do all of these considerations impact what I understand to be a "problem" or "not a problem"? The inclusion of a specific focus on power privilege, identity, and motivation is supported by both the need for building space within engineering culture that allows for consideration of social justice issues [13] and the use of reflection within design practices focused on recognizing power and achieving equity. In addition, having humility has long been recognized as critical for navigating, challenging, and addressing power imbalances [81]. Goodwill's [82] Field Guide to Power

Literacy includes worksheets to help designers conduct "power checks"—including identifying, naming, and understanding the impact of power—at different phases of a design process and the Creative Reaction Lab's [83] Field Guide for Equity-Centered Community Design has reflective prompts for each step of their design model. In addition, Khovanskaya et al. [38, p. 67] offer several questions and provocations—e.g., "What's at stake?", "What is my positionality, power, potential leverage?", "What are the limits of design?"—for use throughout design practice to remind designers of the "human stakes of our work."

The undercurrent, "Sketch, prototype, and test: problems, context, ideas," emphasizes leveraging visual tools, highlights the importance of testing assumptions, understandings, and ideas throughout design work—including through engagement with stakeholders—and acknowledges the ways in which visual tools may be used in combination with various testing strategies. While the Develop stage is a distinct stage in this SED Process Model, where designers are likely leveraging the use of sketches, prototypes, and tests to gather data and feedback on potential solutions, socially engaged design encourages designers to leverage sketches, prototypes, and tests at every stage of a design process. Using sketches, prototypes, and tests throughout a design process includes, for example, crafting interview questions during the Explore stage to test an assumption, or creating a rough prototype to communicate current understanding of the problem during the Define stage, or sketching a service model to think through different aspects of a solution during the Ideate stage, or creating multiple prototypes to conduct usability testing during the Develop stage.

This undercurrent parallels Schön's [73], [84, p. 133] understanding of design as a "reflective conversation with materials"—materials such as sketches and prototypes—whereby designers are reflecting while they are in the process of designing. Numerous prototyping strategies, techniques, guidelines, and best practices have been documented (e.g., [23], [85]–[87]) one research study highlighted 17 prototyping strategies designers can use to engage stakeholders in front-end design activities [88]. Additionally, recent research has shown that prototyping is not a single phase in a design process [10], [89] but rather a "continuous and iterative activity" [9, p. 1]. Lauff et al.'s [89] qualitative study of prototyping across three companies' entire product development cycle and Menold et al.'s [10] literature review align in the assertions that prototypes serve three roles: (1) enabling communication / engagement, (2) supporting decision-making, and (3) aiding / catalyzing learning. Prototypes facilitate communication with both team members and stakeholders [90], [91]. Prototypes are used to understand users and problems [90], in part by enabling observation of user interactions with a potential solution [59]. By situating prototyping as an undercurrent in this SED Process Model, prototypes can be leveraged for communication throughout this process, evidenced-based decisions at each decision point, and everything from exploration of the problem context to exploration of production possibilities.

The undercurrent, "Gather information: social, technical, stakeholders," highlights the regular need to collect information to inform design decisions. To support their reflexive practice, and as a result of constantly visualizing and testing assumptions/ideas, designers will necessarily be gathering new information throughout a design process. This information may relate to designers understanding of themselves, their stakeholders, the problem/solution context, etc. and may come directly from stakeholders—e.g., interviews, observations, usability tests—or from secondary sources such as news articles and databases. Information gathering has been recognized as a critical part of a design process, from defining a problem, to generating solutions, to selecting a concept [31]. This Socially Engaged Design Process Model has an expansive recommendation for what types of information should be gathered because of the importance of understanding complex contexts for successful solution development. Medical device design research has tied insufficient understanding of the context of use with products that have limited impact [92] and recognized the importance of contextual understanding in addressing global health challenges [7]. In addition, researchers have identified consistently gathering information from stakeholders throughout a design process as a recommended practice by synthesizing the literature on information gathering meetings in the fields of engineering design, design ethnography, requirements engineering, and human-computer interaction (HCI) [93].

The undercurrent, "Synthesize: information and resources," acknowledges the variety of information that continually needs to be considered for design decision making. Synthesis is required in any design process, but is especially important in a socially engaged design process because of the amount of information and different types of information constantly being gathered. Designers must make sense of new information in the context of what stage they are in and the information they already have, especially when new information conflicts with or contradicts existing information. The integration of new information into a process may require returning to a previous stage. Gumienny, Lindberg, and Meinel [94, Sec. Introduction] have defined information synthesis as the "practice of integrating, organizing, filtering and evaluating external information [in the design process]" and highlight its importance for both understanding stakeholder needs and solution limitations.

Research Methods

Study Goals. This initial exploratory study is part of a larger research plan that aims, in part, to explore how engineering student designers interpret the role of various design process model visualizations, in general, and potential impacts of design process model visualizations that include people and context, in particular. The goal of our study is to investigate this Socially Engaged Design Process Model's visualization by analyzing the ways in which upper-level mechanical engineering students perceive its visual representation, which is shown in Figure 1, when they are not provided any additional information such as the text description provided in the Background section of this paper. Our research was guided by the following question: What are upper-level mechanical engineering students' perceptions of this Socially Engaged Design Process Model's visualization?

Drawing from the principle of salience in effective visual display design which prescribes making the "most important thematic information salient" [95, p. 467], [96]–[98], we focus on design process model visualizations, because they serve as a proxy for the key aspects of the design processes that they represent. Additional motivations for focusing on visual representations include: visual representations support instructors' in describing and explaining non-linear processes [99], designers may more frequently reference a visual representation of a process model than all available text descriptions, and a focus on visual representations provides clear boundaries for comparing design process models.

Participants. Students were recruited from a public institution in the Midwest. We sent emails to a university listserv for the mechanical engineering department and to engineering student group contacts. Email invitations sent to students included a study description and a link to a short screening survey where they could indicate their interest in participating and provide information about their major-specific design coursework, minors, project teams, co-ops or internships, and demographic information. We limited recruitment to upper-level mechanical engineering students to (1) ensure they had some exposure to design coursework and (2) simplify the number of factors influencing student perceptions for this initial investigation. In alignment with recommendations for exploratory research to begin with small-scale qualitative studies [100], [101], our study consisted of six participants. One recent research example is the data in Jaimes' [102] exploratory study of how the Capital Framework Model explains Latinx scientists' career trajectories consisted of ten semi-structured interviews.

Participants included five fourth-year mechanical engineering students and one fifth-year mechanical engineering student. Five of the six participants had a minor. All six participants had completed the first two of a three-course design and manufacturing sequence, three participants were in the process of completing or had just completed the third course in that sequence, and one participant had completed an elective course on front-end design. All participants had some co-curricular experience with co-ops, internships, and/or project teams. Two participants had seen this SED Process Model's visualization before participating in this study. Participant ages ranged from 20 to 23 years. Demographic information is based on student responses to open-ended questions rather than selection from a predetermined list. Three of the six participants reported their gender as male and three participants reported their gender as female. One participant reported their race/ethnicity as Guyanese, one reported their race/ethnicity as Sephardic Jew, and four participants reported their race/ethnicity as White or Caucasian. Participant characteristics are summarized by recruitment criteria in Table 1.

TABLE 1 Summary of participant characteristics by recruitment criteria

Recruitment Criteria	**Participant Characteristics (Participant Count)**
Year of Undergrad	4 (5); 5 (1)
Major	Mechanical Engineering (6)
Co-Curricular Experience	Co-ops or Internships (4); Project Teams (5)
First Time Seeing this SED Process Model's Visualization	Yes (4); No (2)
Age	20 (1); 21 (2); 22 (2); 23 (1)
Gender	Male (3); Female (3)
Race/Ethnicity	Guyanese (1); Sephardic Jew: Middle Eastern, Hispanic (1); White or Caucasian (4)

Data Collection. Semi-structured interviews were used to investigate participant perceptions of this Socially Engaged Design Process Model's visualization. Interviews allow us to study things that we cannot observe—for example, the meaning people attach to visual representations—by finding out "what is in and on someone else's mind" [101, p. 341]. Semi-structured interviews, in particular, enable consistency in the main questions asked of each participant while providing the flexibility to ask participants specific follow-up questions, probe for more detail, and clarify responses [103]. Further, researchers who compare the effectiveness of different visualizations have also used interview-like approaches where they present people with different visualizations and ask them to describe the visualizations [95].

A single member of our research team conducted all interviews via Zoom, audio-recorded them, and saved the Zoom-generated transcript. The interview protocol included questions about participants' overall impressions of the model, any recommendations they gathered from reviewing the model, important aspects of design missing from the model, and anything that was unclear in each model. Interviews started with an explanation of the limitations of process models—mainly that no one process model can capture everything a designer should do in every design situation—and a description of the format of the interview. Participants were presented with the process model visualization, given time to review the visualization, and then prompted with questions about the visual representation of the model. Importantly, participants were only shown this process model's visualization (Figure 1), its citation (C-SED, 2020), and its name: "Socially Engaged Design Process Model"

Data Analysis. Our data analysis focused on providing a description of participants' perceptions, while recognizing the numerous ways in which individuals may make meaning of this SED Process Model's visualization. This analysis was informed by understanding each participant's perspective as a lens for viewing this process model's visualization and valuing a collection of viewpoints as a way to build of fuller understanding of how this process model's visualization may be understood or leveraged by designers. Identifying themes was particularly relevant to our research question as themes are useful for capturing a variety of perceptions, checking if people are perceiving key aspects of the model as intended, and checking if they have perceptions that were unintended. Thus, we used thematic analysis—a multiple-phase method for identifying themes within data [104]—to explore mechanical engineering students' interview responses and used the outline for thematic analysis provided by Braun and Clarke [104] to guide our own thematic analysis.

Thematic analysis began with one researcher reviewing, correcting, and reformatting the transcripts produced by Zoom while listening to the corresponding interview's audio recording. This researcher imported the data to the NVivo software program and then reread the beginning portion of each participants' interview. She started by coding the data as a "lumper" [105, p. 34], using descriptive and simultaneous coding, as described in [105], to tag when particular aspects of this SED Process Model's visualization were discussed. The researcher conducted a second round of coding, now coding as a "splitter" [106, p. 395], using In Vivo coding, along with descriptive and simultaneous coding, to further investigate the data associated with each of the preliminary codes and start identifying potential themes. Themes and their relevant codes and data extracts were then compiled and reviewed to check their alignment. From this review, three themes were particularly notable in this data set and the first two authors focused further analysis on this subset of themes. In the process of writing up the findings presented below, themes were further refined as quotes from coded extracts were selected to illustrate each theme. Through this clarification process two additional themes were identified, for a total of five themes.

Findings

We identified five prominent themes on how our participants—upper-level mechanical engineering students—perceived this Socially Engaged Design (SED) Process Model's visualization. While these themes inform and relate to one another, we present each theme individually.

Theme 1: All participants perceived this SED Process Model's visualization to include five stages and most participants understood the undercurrents occurred across the stages or regardless of stage.

Within this SED Process Model's visualization, the five stages represent specific parts of a design process, while the four undercurrents represent things that are done across all stages. All six participants recognized or assumed this SED Process Model was shaped by five stages, steps, or categories: Explore, Define, Ideate, Develop, and Realize. Beyond the stages of this SED Process Model, most (5 of 6) of the participants recognized the undercurrents as something a designer would do at each step or stage or as activities within each step. When responding to a question on what this model recommends designers do when engaging in an engineering design process, Participant D said:

It recommends that you kind of have five stages, the Explore, Define, Ideate, Develop, and then Realize. And then within each stage… has kind of four activities that you'll be doing, which [are] the different colored lines… "Reflect and analyze", the "Sketch, prototype, and test", "Gather information", and "Synthesize."

While most participants understood the four undercurrents occurred across the five stages, one participant was confused on how the undercurrents related to the stages. Participant B's impression of this SED Process Model's visualization was:

I'm not too sure what's- what exactly is going on, it seems to have various different layers, like you have all these… what I assumed were five different categories, but then you also have the colors in the background [undercurrents], and those are their own thing. And if you start looking even into those [undercurrents], it just doesn't seem to make that much sense. You go from sketching, prototyping, testing to gathering information and gathering information is kind of done throughout, is what I think. And it's just, it's confusing to me.

And when asked what questions she had about this process model, Participant B said: *How do the blue wave parts [undercurrents] work with the five categories [stages]?*

Theme 2: No participants discussed the ripples as representing unintended consequences and varying levels of complexity. However, there were several interpretations or questions

about relationships between the undercurrents, ripples, and wave shape in the model that did not align with the development team's intentions.

Five participants assumed or questioned whether there was a relationship between undercurrents and the orientation of the wave shape in a particular stage and/or the size or thickness of the ripples. While there was some variation in terms of the specific meaning of the relationship, there was the implication the relationship was mediated by the orientation of the wave/ripples and/or changed from one stage to another.

Three participants wondered whether the wave shape roughly overlaying the undercurrents and/or the thickness or size of the ripples indicated the order in which they should progress through the undercurrents. When Participant F was first discussing the model, he said:

One thing I was going to ask is, which was not entirely clear to me, you know how [the] Explore [stage] is on- on top and [the] Define [stage] is like inverted? Does that mean as we're going through those processes, like when exploring do we start with reflecting and analyzing the power, privilege, and identity, and when we move on to [the] Define [stage] do we start with synthesizing? Or it's still the same steps you take, it's just the graphic is upside down?

Participant C had a similar first impression of this SED Process Model's visualization, sharing:

I have trouble following… for the grading of color from light to dark [undercurrents] whether you're starting at the light and going to the dark or the other way around. And it's almost like . . . I'm going to call them like volume signals [ripples], like I think it's going from the lighter part- the smaller part of the volume signal- yeah I guess that was sort of tricky to follow, because it differs between… each of the steps.

Participant E initially seemed "pretty sure" that this SED Process Model recommended starting with the "Synthesize" undercurrent, and then moving towards "Reflect and analyze." When she was asked to clarify how she knew to start with "Synthesize", she conceded that she didn't know, but that it was what made sense to her and then stated something she had been wondering:

Does the orientation of each… arc shape [ripples and wave] and the direction of the gradient [undercurrents] have some meaning? Are you supposed to go back and forth, like each time?

Two participants thought a relationship among the ripples, undercurrents, and wave orientation may indicate the importance of and/or amount of time spent on particular undercurrents in each stage. When describing his initial impression of the visual representation of this SED Process Model, Participant A said:

And then also just because, like for each stage, for example, [the] Explore stage there's… those dark curves go from like thinner too thick [ripples] it kind of gives me the impression that, in the Explore stage… the Synthesize layer [undercurrent] isn't as important as, the Reflect and Analyze layer [undercurrent]. And then that kind of gets flipped [wave] in the Define stage, like in the Define stage there's less reflecting and analyzation. Then there's a lot more synthesizing of information.

Theme 3: Iteration in design was salient in visual representation of this SED Process Model to participants: All six participants explicitly commented on the iterative nature of this SED Process Model's visualization with respect to movement between stages, and four participants also explicitly mentioned iteration within a stage. In addition, several participants' perceptions indicate the representation of non-linear iteration in this SED Process Model's visualization may be a differentiator from other process models.

In this SED Process Model's visualization, the light gray arrows represent iteration within and between stages, including non-linear movements between stages. Even though the concept of non-linear iteration seemed less familiar to Participant B, she recognized that this model allows for movement between non-adjacent stages, stating:

The arrows within the sets themselves make sense, you sort of, I guess explore throughout, for example. It's just the arrows in between the things don't quite make sense, why would you have an arrow between- Well, I guess that does make sense. It's just you go from exploring [the Explore stage] to ideating [the Ideate stage] and I'm not sure how that exactly would work. It would work, yes. It's just- its- It feels like it's- a bit- I don't know. I guess I'm used to just a more of a linear progression in the process, but, this, it makes sense, but, in, some strange ways.

Participant F highlighted that the iteration within each stage would "ensure" completeness of a stage, while at the same time he acknowledged that iteration between stages could occur in this process model.

One of the things that strikes me… initially, this model is how cyclical the whole process is. There's a lot of iteration and non-linear movement as shown- as it defines the arrows. And it just advises teams, I guess, to just go back. At a lot of steps, they go back, depending on what your end result is just go back.… So, I guess, one thing that will create is, as we move from step, move on to the next step, just- it ensures that you are confident with the work completed in that step, so in that way it's really nice…. once you define [the problem], you take a step back and see… is this problem definition exhausted enough, or is it comprehensive enough, so that when you move from each large step [stage] to the next one, you know for sure that work for that step is completed [inaudible] and also for a lot- a lot of steps you can always go back. I mean once you Ideate you can always go back to exploration or like once you Realize always go back to ideation.

Although two participants did not specifically discuss iteration within a stage, their discussions of iteration did not rule out the possibility of this type of iteration. For example, when describing what this SED Process Model recommends, Participant C focused on movement between steps, saying:

I think what the arrows on top you have to connect- you can kind of go back and forth to the previous steps and adjust based on something you may learn in a later step.

Two participants' descriptions of iteration in this process model suggested that this model's inclusion of non-linear iteration between stages is a differentiator in how participants viewed the overall model, i.e., did they perceive the overall model to be linear? To highlight some of the language that was particularly relevant to this theme, we underlined particular words or phrases in participants' quotes. Participant A discussed how the model recommends adjusting your process based on changing conditions:

[This model] encourages… flexibility… throughout the design process and kind of… emphasizes the fact that the process isn't linear and… as you go through the processes, as things come up in a design... you may find that you need to go to a different stage next. So, for example, you can be at the development [Develop] stage, and then based on something that happens, you might have to go back to the definition [Define] stage and do some more exploration there in order to help make the design better. So, this kind of shows that a design process isn't really something that's… super concrete it's very fluid and it kind of… can take whatever shape it needs to for a design.

Participant D also used language that suggests this SED Process Model has built-in flexibility, describing his first impression of this model as:

It kind of is like a flowing design process, which I personally like just because it's not necessarily- Like while it is like a line, it's not- it kind of emphasizes the flow, that it's sort of a natural progression from each stage and within each stage.

When asked to clarify what he meant by "flowing design process," **Participant D** elaborated:

Instead of what I've experienced in… [first two courses of a three-course design and manufacturing sequence], where it's sort of you have… this hard cut off on a date that… you have to finish this by now, but rather you move along the process how it will occur naturally. So maybe you don't spend as much time on a certain stage because I guess there's- you've gathered enough information and there's not really like a hard cut offs or hard deadlines, but instead you're kind of just moving naturally from between stages and within a stage.

Theme 4: All six participants commented on how this SED Process Model's visualization recommends, "emphasizes," or "implores" a variety of actions and considerations, including: ethical and equitable decision making, reflecting on power, privilege, identity, and motivations, prototyping, gathering information on stakeholders, and understanding context. Sometimes the discussions of recommendations led to positioning certain recommendations as "social" in comparison to "technical" or "engineering" aspects of this process model.

When responding to a question about what this model recommends designers consider, Participant C seemed to focus on one undercurrent (gather information) and interpret "social" as referring to different social groups:

They need to consider the initial- maybe designs that already exist, so getting background information on that. And then I think the social one I think is supposed to be about you know, how this design might affect different social groups so gathering information on that, but that the word social [is] kind of broad so I'm just kind of interpreting that as how it might affect social- different social groups, and then the stakeholders in that situation.

Participant F also discussed how this SED Process Model's visualization recommends designers consider how a design may affect a particular community and described other recommendations, explaining:

One of the things that jumped immediately is that how much it implores sort of designers to look at you know power, privilege, identity, and motivations… You know it's about socially engaged design, right? [rhetorical] So, it implores, at every step it implores you look at again- at what kind of you know societal context, environmental context, and maybe or, you know, the power dynamics and stuff that are in play, so it always implores the designers at each step to sort of take into account the context in which their designing it, so that you don't harm a community or you always keep sort of the primary stakeholders who are going to be affected by this project in mind, or product in mind, so that's one of the things it highlights most I would say

To call attention to some of the language that was particularly relevant in these discussions, we underlined particular words or phrases in participants' quotes. Participant B highlighted that this process model is good "for the intent of focusing on the socially engaged aspects." However, she said:

if you're focusing on the "engineering" aspect of it, it doesn't seem to give enough of- sort of- I guess a process on how to go from idea [the Ideate stage] to design [the Realize stage].

Similarly, Participant E positioned certain recommendations as different to technical recommendations when she said:

I think that's what the… different… definitions of this sort of gradient [undercurrents] recommend… thinking about all available information, and- and gathering it, and making it make sense together, thinking beyond just like technical information and considering who all will be impacted by what you're working on. And then, I think the reflection part is cool because that's not something I like normally hear about, in my work: is like once you done or once you're… not done, but like nearing the end of a given stage you like reflect back on again, not just the technical aspect of what you've done so far, but the impacts of it and how it will sort of affect different conditions that you're interested in.

When asked about what recommendations there are for how designers consider the things she just talked about, Participant E said:

From what I can tell, just… thinking about it, like keeping it in mind. And then, especially considering those things at the decision points, like throughout your work as well, but… focusing on those decisions as opposed to just technical information at each decision point.

Theme 5: Four participants described that while there are these various recommendations, they felt this SED Process Model's visualization did not specify exactly how to achieve these recommendations and a couple participants' discussions suggested that without directions on how to achieve specific recommendations, it could be hard for less experienced designers to follow or use this SED Process Model.

For example, Participant D said:

[This model] kind of emphasizes ethics and then equitable design. And also, I think there's a- emphasis on…considering… social implications and stakeholders, just because sort of "Gather information" is going into each stage. And kind of that's an additional consideration that can be used, I guess, to- to consider ethics and equitable design.

However, he did not think the model conveyed exactly how designers do that "but just sort of that it should be done."

Participant B said that this process model "seems to mostly focus on the social aspects of it," further describing the model as "audience-based" and "focused more so on the receiving end I guess the design, as opposed to the process itself." She acknowledged that the main recommendation "would be to mostly keep in mind, while you're designing that and then... research." Participant B later described the undercurrents as "almost all of them are basically research."

One thing, it says, at the decision points it highlights that you know it should be evidence based, ethical, and equitable, so it should be just and it should be evidence based so it's objective. But you know, especially for inexperienced…. engineers… I don't think that means much. You know, it talks about how you Sketch and prototype problems context, and ideas, but if you don't know a lot about prototyping, you may not be say [inaudible] do that properly, so I don't think it gives clear definitions of how some of these steps can be implemented it just gives the overall idea, I would say.

At times, Participant F's discussion of experience also presented alternative interpretations of the ripples (see Theme 2). For example, he said:

We see that in each- like in [the] Explore [stage], there's four levels of you know arcs or like the Wi-Fi symbol [ripples], so I'm guessing [inaudible] those smaller steps are not defined, so it could be hard for teams to-, especially inexperienced teams, to actually use this process in their projects.

Participant D had questions about "how to do some of the activities" and shared that if he did not have experience in front-end design, "Especially coming from just the very linear design process in- for various projects, which for me were *[first two courses of a three-course design and manufacturing sequence]*," it could be difficult to understand how to do what this model prescribes.

While Participant B did not specifically mention experience, she did talk about how it seemed this model was missing some guidance that could benefit designers, sharing:

It seems like there would be something in between the two [the Ideate and Develop stages] that would, help you go from something- some idea on paper over to some- some thing ["thing" emphasized].

This critique of the model is also connected to Participant B's critique of the model as not being as good if focused on "engineering" aspects versus if focused on "socially engaged aspects" (see Theme 4).

Discussion

Our analysis revealed some themes related to interpretations participants had of what the Socially Engaged Design Process Model's visualization included and recommended designers do. We discuss these themes in the context of prior literature and implications for the model itself as well as educators using design process model visualizations of any kind.

Participant perceptions of undercurrents. Participants' impressions of this Socially Engaged Design Process Model's visualization included wondering about whether there was a particular order to the four undercurrents: Reflect and analyze; Sketch, prototype, and test; Gather information; and Synthesize, whether certain undercurrents should be allotted more time when doing design work or were more important, and whether order, importance, or timing changed from one stage of design work to another. The developers of this SED Process Model did not intend to prescribe a particular order to complete the undercurrents or that the ordering, timing, or importance of undercurrents always varies in a particular way based on the design stage. Indeed, research has established that designers engage in multiple activities that align with the emphases of the undercurrents, throughout their design processes [62], [107]–[109], and the wave shape of this model is intended to acknowledge that a design does not occur in a linear path from exploring potential problems to an appropriate solution.

We suggest several reasons why participants may have wondered about the ordering of undercurrents. One reason is that if participants have prior knowledge of activity-based or combined models that present activities as cyclic/occurring iteratively or even the classification scheme of stage-based versus activity-based models [5], [110], they may be adding that prior knowledge to their understanding of this SED Process Model. Cook [111] argues that prior knowledge impacts learners' interpretations of visual representations, in part because learners are adding information based on their prior knowledge [112]. While this SED Process Model does parallel combined models in some ways, as noted in the Background section—e.g., analysis, synthesis, and evaluation reoccurs several times in any given design process [79], it diverges from the stage-based versus activity-based classification scheme [5], [110] in that it does not prescribe an order to or discretization of the undercurrents.

Another reason participants may have questioned the order of activities specified by the undercurrents could be the types of models participants have been exposed to or have experience with. For example, if participants are more familiar with representations that present analysis, synthesis, and evaluation as discrete steps or, more generally, if they are familiar with linear representations of design processes with sequential steps, rather than having familiarity with a variety of ways in which a design process can flow. In Dubberly's [4] compendium of design models, he noted that in 1962 Jones proposed: analysis, synthesis, evaluation, as a "basic framework for design processes" (p. 19) and Dubberly acknowledged several questions regarding how these steps relate to each other. Models in this compendium include oscillation between analysis and synthesis, a progression from analysis to synthesis or synthesis to analysis, and a shift in focus from analysis to synthesis.

Participant perceptions of iteration. A salient aspect of this SED Process Model's visualization was iteration, particularly non-linear iteration between stages. Iteration may be a salient aspect of this SED Process Model's visualization in part because iteration is an integral part of any design process that seeks to address complex problems and by nature of its focus on sociotechnical problems this SED Process Model aims to address problems that include the complexity of social systems. Wynn and Eckerts' [68] integrative literature review of iteration in design and development demonstrates iteration is common in ambiguous situations and may lead to better designs. Another reason iteration may be a salient aspect of this SED Process Model's visualization is our student participants may recognize that iteration is an indicator of effective design practice. Jin and Chusilp [113] found that having more iterations and spending more time on each iteration usually led to higher quality concepts. Similarly, in Adams' exploration of iteration among 16 freshman and 16 senior student designers, seniors engaged in more effective iterative behaviors —including spending more time on iteration and having more iterations [70].

Furthermore, a couple participants' perceptions seem to suggest the non-linear iteration represented in this SED Process Model's visualization is a differentiator from other process models, even ones that include iteration. Building from Yang's [114] understanding that design "might include either a rigid or flexible process," if we think of iteration representations on a continuum from rigid to flexible, perhaps this SED Process Model's visualization is closer to the "flexible" end. In contrast, a visualization of a process model such as French's [1, Fig. 1.1] where feedback is always from later phases to earlier phases would be closer to the "rigid" end. From this perspective, our finding that more flexible representations are a potential differentiator would align with McKenna's [115] adjacent finding of a lack of support for flexibility in existing data visualization design models.

Participant perceptions of model recommendations. Some participant discussions of what this SED Process Model's visualization recommended highlighted how prescriptive this SED Process Model is and who may be able to use this model. Our findings suggest that the visual representation of this SED Process Model is useful in prompting students to at least "keep in mind" things such as "social implications and stakeholders" (Participant D), "social aspects" (Participant B), and "not just the technical aspect of what you've done" (Participant E). Although participant responses suggest that while this model does prescribe certain things, it could be more prescriptive. For example, Participant F shared that the model highlights decision points "should be evidence based, ethical, and equitable", but he did not think the model gave "clear definitions of how some of these steps can be implemented."

Though prescriptive and descriptive process models are sometimes described as two distinct categories—where descriptive process models capture what designers actually do and prescriptive models convey what designers should do—(e.g., [116]), a single process model can have prescriptive and descriptive traits [26], [27]. So, while we already know models can span a continuum from descriptive to prescriptive, our findings also suggest that there is also a continuum within prescriptive models that characterizes to what degree a process model is prescriptive. While this SED Process Model's visualization is helpful for prescribing certain things to do and consider, it may be less helpful for designers who are not familiar with certain activities (e.g., how to prototype) or know methods to support specific considerations (e.g., how to gather stakeholder input).

Furthermore, from participant's discussions of what this model recommended, it seems that the model is highlighting how some participants put "engineering" or "technical" at odds with "social." This tension aligns with the prevalence of technical/social dualism in engineering culture (e.g., [117], [118]). Since we are already seeing students pick up on some ways in which this model is covering broader considerations than what they have previously experienced, the visualization of this SED Process Model has potential to expand conceptions of what engineering is, if it's integrated in courses and presented as a model applicable to engineering design.

Implications for this Socially Engaged Design Process Model's Visualization. One implication is this SED Process Model's visualization might need to change in how it conveys uncertainty as well as various levels of complexity because no participants included these aspects in their discussions of the model. In addition, the way the visual representation of this SED Process Model intended to convey uncertainty and varying levels of complexity appeared to instead convey unintended relationships between the undercurrents and the wave shape and/or the ripples. Another implication is we should consider how the visual representation conveys that while designers are generally moving from the Explore stage to the Realize stage this path is not necessarily going to be straight or uniform because (1) the presence of the iteration arrows seems already to be prompting students to recognize the flexibility and variability that the model affords and (2) the inclusion of the wave shape is contributing to unintended perceptions of the model.

Implications for Educators. Our initial exploration of students' perceptions of this SED Process Model's visualization suggests that including this model in curricula could convey (1) an iterative design process and (2) a flexible design process. We suggest educators consider not only using a collection of process models to emphasize the lack of a singular, definitive design process, but also the variety conveyed in their collection of process model visualizations in terms of their representation of both iteration and flexibility. Particularly for beginning designers, if they are relying on a single process model with no representation of iteration they may treat design as a linear process, as seen in [119]. Design process model visualizations that incorporate relatively large amount of flexibility may help scaffold student learning to the point of being able to strategically manage their own design processes—a characteristic of "informed designers" [120]—and opportunistically deviate from prescriptions—a characteristic of expert designers [121].

In addition, educators should consider how the role of a single design process model's visualization may change with use context. Our findings suggest this SED Process Model's visualization may be useful for expanding less experienced engineering designers' conceptualization of what is "engineering design," but additional scaffolding would be needed for such students to then act on that understanding. For more experienced designers, this SED Process Model's visualization may serve as flexible guidance with reminders to consider social context and stakeholders in addition to/alongside technical considerations.

Limitations. One limitation of our study is that we are only capturing participant's perceptions of this SED Process Model's visualization after they have had a few minutes of taking in the model and writing some notes about what the model recommends they do or consider when designing. Participants may jump to conclusions that they may reassess if given more time or the chance to engage in a design process that is supported by this SED Process Model.

Another limitation is that we only shared this process model's visualization (Figure 1), its citation (C-SED, 2020), and its name: "Socially Engaged Design Process Model" with participants. Thus, our findings are based on participants' responses who did not have the benefit of referring to a text-based description of this SED Process Model, such as what is provided in the background section of this paper.

Conclusions

Our study explored mechanical engineering students' perceptions of this Socially Engaged Design (SED) Process Model's visualization. We conducted semi-structured interviews with six participants who saw only the visual representation of this SED Process Model; not a text-based description such as our description of this SED Process Model provided in the background section of this paper. From our thematic analysis of participants' interview transcripts, we identified five themes on how our participants perceived the visual representation of this process model. These themes include unintended interpretations of the model, salient aspects of the model, and model recommendations. These findings have several implications for the model's visualization including the opportunity to clarify the meaning associated with the ripples and wave shape. In addition, the findings highlight several considerations for educators who are leveraging any kind of design process model.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2013410. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors would like to express their gratitude to Robert P. Loweth for his feedback on a draft of this paper.

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