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Conceptions of design by transdisciplinary educators: disciplinary background and pedagogical engagement

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Abstract
In this study, we describe similarities and differences in how faculty members from across disciplinary backgrounds conceptualize design. The study is situated in an innovative transdisciplinary undergraduate degree program centered on a studio-based learning experience co-taught by multi-disciplinary faculty. While faculty celebrated the opportunity to integrate multiple disciplinary perspectives, they showed a lack of awareness about differences in how they conceptualized design and design pedagogy, especially early on. In-depth interviews and sketches of eight faculty members provided insights on alignment around core concepts of design, design process, and design instruction. Common themes in design definitions included creation of something new, human-centered design, and focus on problem framing over solution development. There was disagreement on the relationship between design and other ways of knowing, such as problem solving and scientific reasoning. Most used process models incorporating non-linearity, iteration, prototyping, and balance between research and design ideation. While there were many similarities in teaching approach, the rationale given for decisions varied, highlighting underlying differences in how participants thought about teaching design. Instructional alignment is an important consideration in designing a transdisciplinary learning experience, but may be hard to achieve due to cultural and institutional disciplinary boundaries. Collaborative teaching efforts benefit when faculty engage in self-reflection, discussion, and engagement in meaningful synthesis work related to understanding what design is and how it can be taught. Such work will enable a team to create purposeful learning experiences which leverages the benefits of exposure to a range of design problems, contexts, users, and design "flavors."

Keywords Design models · Studio education · Design education · Transdisciplinarity · Definitions of design

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Design is an important aspect of engineering theory, education, and practice (Adams et al. 2011; Daly et al. 2012; Sheppard et al. 2008). However, conceptualizations of design, *especially* within engineering, vary widely based on individuals' philosophical orientations and areas of disciplinary specialization of individuals (cf., Cross and Cross 1998; Dym and Little 1994; Pahl et al. 2007; Pawley 2009). Such variation can be problematic when differences are not recognized, acknowledged, and explained to students. Overcoming differences between individual faculty members' understanding and definitions of design may become even more difficult within traditional higher educational institutions—particularly large public research-intensive universities, where cultural and institutional barriers result in disciplinary silos (Schön 1995). Those barriers have historically limited opportunities to draw together faculty from diverse disciplinary backgrounds in ways that are egalitarian and discipline-agnostic (e.g., Russell et al. 2008). Such multiple disciplinary perspectives are critical to aiding the development of students' design identities and are critical to addressing the complex challenges envisioned for the future of technology and design. Therefore, understanding the complementary views of design that faculty share is therefore critical to scaffolding the development of student design ability.

In this study, we interviewed faculty that engaged in an innovative transdisciplinary undergraduate degree program. The program encourages students to understand and activate both technical and humanistic skills and knowledge to address "wicked" problems in a design-centric way. The program relies on design philosophies (e.g., human-centered design) and pedagogical emphases (e.g., studio pedagogy). The faculty spent significant time co-designing the program-level experience. During this process, there seemed to be an implicit assumption that the group members held similar understandings of concepts related to design and how those concepts may be operationalized in the classroom. Changes in faculty membership occurred over the following years, but no in-depth conversation was held about these topics. As the program evolved, evidence from student feedback and informal conversations among individual faculty members challenged the assumption that there was a common understanding of, or way of teaching, design and related topics. This realization inspired the present study, in which we use this program as a platform to describe and analyze the nature of alignment around core concepts of design and design process, identifying instances where definitions converge and diverge, and the impact of these differing definitions on pedagogical experiences.

Background

Definitions of design

Approaches to education in engineering and technology have not engaged consistently with the epistemological underpinnings of the relevant disciplines (de Figueiredo 2008; Hynes and Swenson 2013). One result of this lack of ongoing discourse is ambiguity over the meaning of design, and the operationalization of design concepts in informing pedagogical decisions (e.g., Dym et al. 2005; Ledewitz 1985; Roozenburg and Cross 1991). This tension between ambiguity over the meaning of design and the activation of design in curricula is important because conceptualizations of design have implications for how faculty relate to or guide students' identity formation as designers. The lack of consensus on definitions of design is not limited to engineering and technology education. Rather, it is evidence of historic undertheorization of design in both disciplinary and transdisciplinary framings (Cross 2007; Fallman 2003; Nelson

and Stolterman 2012; Roozenburg and Cross 1991)—a situation complicated by inconsistent use of the word *design* and related terminology. Further, the concept of design often serves a discipline-agnostic, metanarrative role (e.g., Buchanan 2015; Kolko 2018) that disguises differences in disciplinary design boundaries; for instance, the call for "design thinking" encourages discussions of design that avoid discussing disciplinary distinctives or implementation challenges. In addition, other approaches to incorporate design-related commitments, utilizing lenses such as liberal education, ethics, or criticality, have often been marginalized in the traditional engineering and technology discourse.

Studio education and design models

Studio education as a mechanism for inculcating students' design ability has a long history in academia (Brandt et al. 2013; Gray 2016). However, existing literature regarding student learning of design as an epistemology and means of acting in the world has not consistently engaged with multiple disciplinary perspectives or ways of viewing design activity, even as scholars have called for such work to be done (e.g., Buchanan 2001; Ledewitz 1985).

A siloing of design disciplines, as well as the common use of approaches to design learning that still rely on relatively rigid process models of design behavior (e.g., Yazdani 1999), have potentially resulted in a lack of transdisciplinary approaches to describing design activity and the development of design ability. This appears to be particularly true in technical domains such as engineering and technology. While there are many models of design processes (cf., Dubberly 2004), it is unclear how these processes—and the conceptions that underlie them—should be taught to students at various levels of development. Relatively little literature addresses the beliefs and conceptions of design on the instructor and disciplinary level (see McLain 2017; Gray 2014 for rare examples), particularly in relation to the activation of these conceptions of process within design pedagogy.

Mawson (2003) has provided a critique of process-focused educational initiatives, offering alternative pedagogical strategies for engagement. This approach is conceptually aligned with critiques of "design thinking" and commoditized views of design activity such Kolko (2018), which has called for an abandonment of such simplistic views of in favor of intellectually rich approaches to design. There are several points of helpful triangulation in the design education literature that moves beyond these simplistic notions of design process and activity, which we will briefly mention here. Boling et al. (2013) have described the role of the instructor in shaping narratives that influence design learning, underscoring the experiential dimensions of engaging in design processes. Gray and Siegel (2014) analyzed the evolution of students' understanding of design process through iterative sketching activities, showing their growing conceptions of design. Perhaps most resonant with the aims of the present study, McLain (2017) has provided a critique of current studio practices, identifying the role of teacher beliefs in activating design learning. Since the role of the instructor is so important in teaching design, it is especially important that instructors be mindful of and reflective about the way they define, teach, and enculturate conceptions of design and design processes.

Purpose of the study

The purpose of this study is to explore the similarities and differences in how faculty members with differing backgrounds understand design. This study expands upon previous work on the changing attitudes towards design and design processes in a range of disciplines. By

understanding how faculty conceptualize design, we can assess the potential for misalignment on a design-dependent educational environment. The study was motivated by the researchers' observations of an apparent lack of alignment across the faculty group. This led the authors to seek a deeper understanding of the groups' conceptions and operationalization of design as well as their use of design terminology and processes in their teaching. The following research questions are addressed in this study:

1. How do faculty members conceptualize design and the design process?
2. How are definitions of design activated in a transdisciplinary educational context?

Method

Context and participants

For the study, we conducted semi-structured interviews with eight faculty that taught in transdisciplinary undergraduate degree program at a large research-intensive university in the United States [An extended description of the program appears in Exter et al. (2015, 2017), Varner et al. (in press)]. In addition to teaching in the program, each participant was either involved in the initial design of the program, or played a role in the design of the learning experience for at least one semester. This degree program is intended to provide students with a self-directed learning experience that engages a range of disciplinary perspectives with explicit inclusion of both technology and liberal education perspectives. Students enroll in courses within self-selected focus areas, while also engaging in a team-taught, integrated learning experience each semester. The learning experience includes seminar-style discussions on diverse topics and a studio-focused project-based curricula that engaged students in synthesizing design, liberal arts, and technical perspectives. The eight participants interviewed in this study originated from a variety of fields, including communications, engineering technology, engineering education, English, human computer interaction design, library science, and theatre technology. Each participant had some form of interdisciplinary background, and the majority held degrees in at least two fields. All faculty who had taught in the prior 2 years of the new degree program were included as participants in this study.

Data collection

We collected data for this study as part of a larger semi-structured interview protocol designed to take 60–90 min to complete. The interview questions relevant to this study included:

- How do you define "design"?
- How/do you explain the concept of design to your TST students?
- What design process do you focus on in your teaching?
- What are the most important aspects of design that you want your students to know and remember?

In keeping with semi-structured interview norms, the interviewers asked follow-up questions to clarify and draw out additional detail, while allowing participants to guide the

discussion. Our primary role as researchers was to draw out and encourage elaboration of participant responses.

The first author was the primary interviewer. The second author sat in on two interviews; in those cases, the first author conducted the interview and the second author asked some follow—up questions. Participants were offered paper and drawing materials to illustrate their points, if desired. The interviews were contextualized within multiple years of ethnographic engagement with the transdisciplinary program. They occurred as a part of a larger program research and evaluation effort led by the first two authors. Thus, the researchers had deep knowledge of common pedagogical practices and student experiences within the program. Independent of this study, the faculty and research teams regularly communicated through weekly meetings and interviews every semester. As former instructors in the program, the second and third authors of this paper were included as interviewees, as they had previously taught in the program.

During the interview, each participant was asked to define 'design' and describe the design process they worked to foster within the program. Through a series of follow-up questions, using a topic domain approach (Carspecken 1996), we attempted to identify the source and rationale for participants' definition of design. Using this definition, we engaged the participant in describing the implications of their view of design for their approach to teaching in general, and their activation of design in the context of the transdisciplinary program in particular. Participants' elaboration of design definitions was used as a way to concretize the conversation about design in this unique educational context, highlighting tensions inherent in the transdisciplinary curriculum.

Analysis

Audio recordings of each interview were professionally transcribed. Using a bottom-up thematic analysis approach (Braun and Clarke 2006), the first author (who was not interviewed as part of the study) conducted an initial round of coding of the interview transcripts, first locating emergent themes through an open coding approach, and then later using these themes to determine patterns of similarities and differences within and across interviews. These themes were then discussed and refined by all researchers based on their prior ethnographic engagement in the learning context. Based on the broader ethnographic engagement of the researchers in the program, we came to agreement that the resulting themes allowed us to describe the range of responses and articulate differences in beliefs as they impacted participants' operationalization of design in transdisciplinary program.

Role and background of the authors

This study was part of a larger ongoing research and evaluation effort related to this program. The program itself was seen as an incubator for trying out novel pedagogical models, and had an embedded research and evaluation team. The initiative was structured such that any team member currently teaching did not take part in student data collection or observation during the semester they taught. However, from the standpoint of the program as a whole, it was seen as beneficial that the research team remain closely tied with, although independent of, the teaching team. The intent of those ties was ensuring that data collection was steeped in a deep understanding of the context and participants. Faculty members across both research and teaching teams maintained a friendly, collegial relationship, and all were involved in program-level curricular design efforts.

Each of the authors for this study brings a unique, interdisciplinary background which impacted their interest in and understanding of the topics covered in this paper. The first author has a background in software design and development and instructional design, and research interest in novel approaches to computing and technical education, including transdisciplinarity and use of studio pedagogy. She has led the research and evaluation team for over 5 years. During that time, she has observed (and been a part of) many discussions among faculty members that pointed to potential discrepancies in how faculty members understood and taught design. These observations were the impetus for this study.

The second author has a background in graphic design, instructional design, and human–computer interaction, and has research interests that relate to professional identify formation, design theory, critique, and studio pedagogy. He previously co-led the research and evaluation for 2 years and was involved in related research efforts at the time of the interviews conducted in this paper.

The third author has a background including time as an engineer in industry, an entrepreneurship and engineering instructor, and an engineering education researcher. His research interests focus on the development of and influences on students' beliefs about knowledge and learning. He was not a member of the research and evaluation team, but was involved with teaching for two consecutive semesters during the third year of the program as a graduate teaching assistant. He was not involved in the initial design of the program, but was involved in several efforts to standardize and solidify student assessment efforts that formed cornerstones of the program.

During the timeframe covered by this study, the first author did not teach and was not interviewed. The second and third authors did teach, and were each interviewed by the first author. The interviews were conducted following a semi-structured interview protocol designed by the first author and her research team, independent of the other two authors. The second author served as second interviewer on two of the interviews as part of his role on the research and evaluation team, and asked some follow-up questions similar to those asked by the first author in other interviews. As described above, the first author conducted the initial analysis, after which the second and third authors iteratively reviewed the themes. The background and expertise of the second and third authors enabled them to give insightful feedback on the themes found in the analysis conducted by the first author, which were then integrated into the final analysis.

The author-instructors' background, rather than introducing bias, helped to hone them as "human instruments" (Lincoln and Guba 1985), and, in turn, helped the first author refine and enrich her own understanding of the data. Her perspective was also informed by her observations of the classroom and previous interviews with participants as part of the larger research and evaluation effort.

Findings

Faculty conceptualization of design and the design process

In this section, we will discuss how participants defined design and the degree to which their definitions aligned. Then, we will discuss how they differentiated design from other ways of knowing. Finally, we will present the ways faculty conceptualize the design process.

Defining design

Several participants found they had difficulty defining design. Those who had no formal experience in design or technology education prior to being part of this program were initially tentative to give a definition. One explained, "My own thinking is so vague and amorphous… especially for those of us that don't come from a design background, we're sort of figuring it out as we go" *[H].* Those with a formal background also indicated they struggled with providing a definition. One laughed, "I chuckle because that is clearly a fraught question… in my experience, design is the process of coming up with…tangible solutions to complicated problems, and that is way too broad a statement to be useful" *[A].* Another similarly explained that "if you force me to do this, it would be something incredibly abstract" *[G].*

When asked "how do you define design?" the definitions that participants provided differed meaningfully, even between instructors who had co-taught. Several individuals gave a definition of design that focused on creation; for example, one defined design as "[the] manner in which you create something through the process of planning and creation and revision" *[D].* Another emphasized the importance of not limiting design to one particular type of creation: "I find [design] to be synonymous with creation. I don't want to get too specific about what it is that a person is creating when they're designing because I think […] that could be anything" *[E].* Being part of this program had an impact on how participants thought about design, particularly those from non-design backgrounds. One who had a background in gender studies and English explained:

> I guess, because what I think about design is happening and growing inside of this program. It's informed by this idea of systems and transdisciplinary in a way that it might not otherwise be. I think if you had asked me before "What is design?" I would have thought things that were more technical, maybe having to do with how things move through and interact with space, how human beings… interact with spaces and things, but I guess my thinking around design… one of the things you hear about design is it's this idea of human centered solutions, maybe, and I don't know that I really, I'm not necessarily on board with that. Especially in terms of systems, I think we should be thinking about the design of systems; how elements of systems are working together….But, I also think of design, I guess, as a process; so in designing the curriculum for the coming year, one of the goals was to have students think about iteration and how design happens over a course of time and according to different users, multiple different users, multiple different ways of knowing, so how is design always in process. [H]

Most participants stressed the importance of defining a problem and scope, making solutions secondary and de-emphasizing the process of "building" or creating a finalized product. As one explained, "I think the actual making of an object is way down on the list. I think there are so many things you have to do before you get to that point" *[E].* Two participants said that an important aspect of design is the "co-creation of understanding of the problem and solution" in which the designer "is willing to use their attempts to solve a problem to create a new model of understanding of the problem while they're creating a solution" *[G].*

Finally, all but one participant stressed the importance of human-centered design, or designing with users in mind. They talked not only about how the design might impact users, but also how users could influence the design. Some stressed that this goes

beyond human users, including animals, the environment, and other systems, as well as the importance of considering context of use. As one explained, as she planned and taught for this program, her idea of what design is changed:

> I think if you had asked me before [designing and teaching a semester of this course] "What is design?" I would have thought things that were more technical, maybe having to do with how things move through and interact with space, how human beings…interact with spaces and things, but I guess my thinking around design, I mean, it still is those things, but…one of the things you hear about design is it's this idea of human centered solutions…. I'm not necessarily on board with that. Especially in terms of systems, I think we should be thinking about the design of systems; how elements of systems are working together. We're teaching hive architecture, how do bees design things, and ants design things, so how do objects themselves interact with space. How are animals users of design. But, I also think of design, I guess, as a process; so in designing the curriculum for the coming year, one of the goals was to have students think about iteration and how design happens over a course of time and according to different users, multiple different users, multiple different ways of knowing, so how is design always in process. [H]

Although there was variation across definitions given by the multi-disciplinary faculty group, differences did not seem clearly tied to disciplinary backgrounds. Participants with a strong background in design were more likely to use more sophisticated and precise language when discussing design, but the traits discussed above were spread across participants with backgrounds in design, technology/engineering fields, and humanities. While some were concerned about mismatch in how program faculty conceived of design, one pointed out that this could be construed as an advantage: "I'm not sure that's a bad thing. I mean, that's inherent in what we're trying to do in a transdisciplinary program" *[B].* She went on to explain that while her definition of design may be closer to that of other faculty with engineering backgrounds, she felt that the faculty with humanities backgrounds "don't give themselves enough credit for their level of technological understanding and some of the things that would classify as design" *[B].*

Distinguishing design from other ways of knowing

Participants also discussed how design related to other concepts, frequently comparing or contrasting designerly ways of knowing with other disciplinary forms of knowledge. Several discussed the relationship between design and problem solving. As one recalled, "I can point to a very heated and contested conversation that the faculty had last summer about what design means and how that's related to problem solving" *[A].* This conversation had revealed deep differences of opinion in relation to design's role as simply one form of problem-solving behavior (with parallels to engineering design processes) or design as a unique way of knowing and acting. One suggested that design is "the application of abductive problem solving and the techniques of those who have demonstrated such expertise to problems that generally blend socio-technical things" *[G].* Another indicated that design is a type of problem solving, but distinguished problem solving from more "procedural" efforts such as trouble-shooting. Although that participant strongly distinguished problem solving from the scientific method, he indicated that something like the scientific method could be incorporated within the design process:

Several compared design to science, or design process to the scientific method. One argued that design is "most easily distinguished from scientific approaches, which are focused on understanding the world as it is and design is focused on changing the world" *[F].* However, another described design process as

> like a blown-up scientific method, which is like to figure out, identify the issue, look at past data on how people tried to maybe work with the issue, come up with maybe new things both on the research they've done, examine those, narrow it down, prototype it, examine the prototype and go back 1 step, do that again off of your prototype data, try a new prototype. [C]

While a third clearly distinguished between design, problem solving, and scientific method, he also drew parallels between what he called the detailed design phase and the scientific method: "So, for, a machine design problem, that's a whole bunch of analyses of the forces and torques and power involved, and can I generate enough power? Can I provide enough torque? etc." *[A].*

This difference between viewing design as more in line with science, or with relationship to an activist or pragmatist stance, also seemed to cut across both technology-focused and humanities participants, often as a matter of focus. In line with a less scientized view of design, participants generally distinguished design from other endeavors as being focused on the needs of users and context and the ability to defend a decision made, rather than finding an answer that is right or wrong.

Models and components of design processes

When discussing the design process, the majority of participants believed that there is a largely universal design process. Several participants pointed out how differences in problem, users, context, or other constraints could have an impact on the "flavor" of design process but that the larger sequence of events is generally the same. For example, one participant explained:

> The concept of design has different applications in different contexts, and I think that that's really important to recognize, right? Database design is a different process than set design, for example, though both are the development of some kind of a solution to a specific problem. [A]

This participant went on to explain that when designing theatre shows, designs must be put together quickly and fit the needs of the show, but do not have to last very long or withstand continuous use, in contrast to solutions in other domains that must be maintainable and sustainable. Thus, the disciplinary context of design had the potential to emphasize certain portions of the design process or the nature of design outcomes differently.

In contrast to the other participants, one individual argued:

> I don't believe [disciplinary design processes are] at all the same thing… you can't just summarize design into A, B and C. There's going to be very specific theories and knowledge… You want to understand how deep a discipline can go traditionally and we want to present them with many different views [D].

This response indicated a belief that the basic nature of design processes *must* vary between and within disciplines.

Participants were given the opportunity to sketch their vision of the design process. Most opted to sketch a design processes or shared a diagram of a published model as part of talking through their conceptions of design. Frequently, the core sketch created by participants continued to be used to point out certain areas of focus, with addition of extra arrows, loops, or other annotations. The number and names of steps articulated by the participants varied. One shared a diagram of a generalized 4-phase model that he felt was particularly appropriate for teaching purposes, as it was simple and could be used across domains (Fig. 1a), although the terminology used in the model as he used it within instruction in his own program was engineering-focused (Design Specifications, Conceptual Design, Detailed Design, and Design for Implementation (replacing "manufacture" in the original published model). He then discussed how the process actually occurs, "the process is messy, right? You start and stop at all sorts of weird places and backtrack at all sorts of weird times" *[A]* (Fig. 1b). Another used her sketch as a means to "verbalize" her own thoughts about the messy process as she saw it, using terms such as "playing", "exploring", and "drawing"; adding many arrows to show how steps could be back-tracked or skipped; and finally adding "critique", indicating that this could occur at any point (Fig. 2; [H]). One participant initially drew a design process, then indicated his frustration with the idea of focusing on this type of process model (Fig. 3a), saying "let's talk about how we can abstract this all the way back to, not even a generalized design process, but a generalized thinking process" *[G].* He then sketched his vision of this "meaning-making process" (Fig. 3b).

Several aspects of the process appeared to be common across many participants. While not all used the term "problem framing," most discussed the importance of understanding the problem and context in which design occurs and the ways in which these factors constrained the problem space. One explained this using terminology from mechanical engineering:

> The specifications are really the framing of the problem, right? What do we need to and what are the constraints that surround our solution set?… What is the thing I'm making need to do? And then, we also talk about things like what are the skillsets of the people I have who are going to make the thing? What are the skillsets of the people I have who are going to run the thing? Does this thing need to go into a small theater or a big theater? Do I need to worry about access ways and doorways? Is this going to perform for three years or three weeks? Do I have $30 or $3 million? All of these things, right? You sort of frame the problem within all of the desires and the constraints…[A]

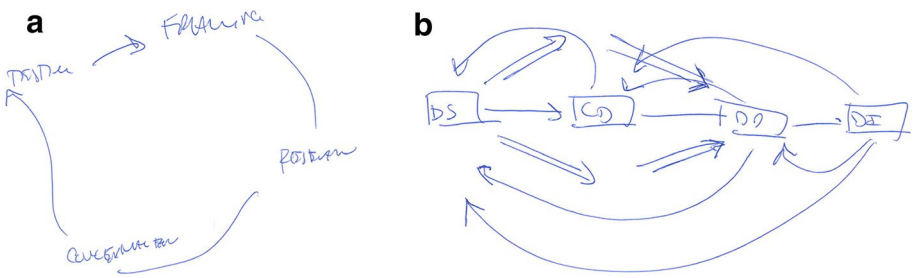

Fig. 1 **a** Four phase process, based on a published model (terms translated into those used in class). **b** Process in practice: designer can move between phases in many directions [A]

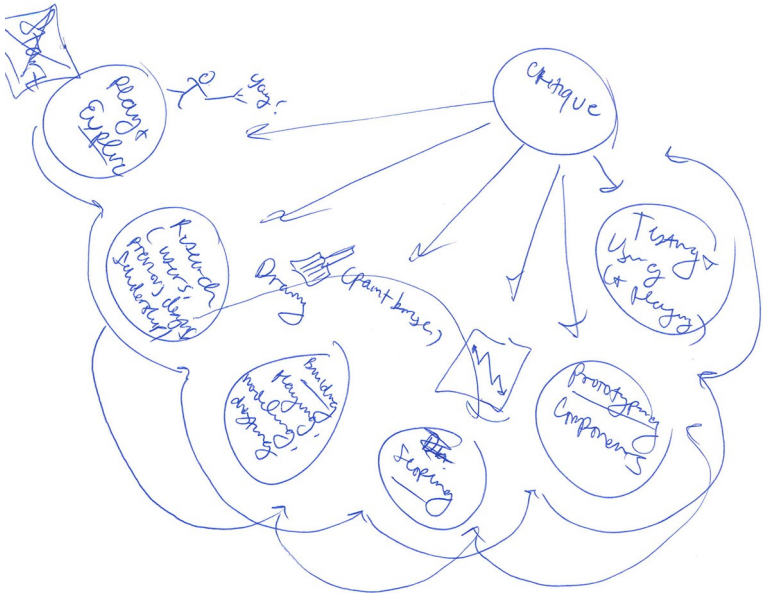

Fig. 2 Process created to elaborate on interview discussion. This participant stressed that a designer could and should move frequently between the design activities, and specifically added "playing" in multiple areas, as well as "critique" connecting to all parts of the process [H]

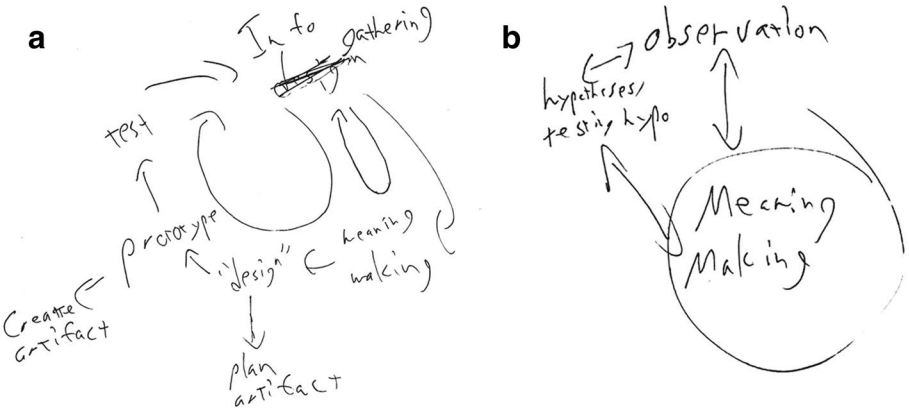

Fig. 3 **a** Initial sketch of the design process. As the participant discussed this process, he identified that the focus should really be on the meaning-making aspects of design behavior. **b** He then emphasized that the real focus is on a 'meaning making' cycle [G]

All participants indicated the value of ongoing cyles of research, although the specifics of what this entailed varied from a critical review of traditional written sources, to investigating existing products, to prototyping and user testing. Aligning with the emphasis on human-centered design or "understanding the user" in their definitions of design, the majority stressed the importance of addressing users and context within the process, referring variously to the need to identify users and stakeholders correctly; focus on real needs

and constraints; express empathy for users; and understanding the surrounding of context and culture. Seven of eight participants mentioned or implied the importance of user research to inform design. One pointed out that such research has to happen not only at the beginning, but also throughout the process, suggesting to students, "let's research how it's working. Let's ask our users is this prototype working for you? What could make it better?' That research part is throughout it" *[E].*

Several participants stressed the importance of ideation, or coming up with multiple divergent design concepts. As one explained:

> We spend some time coming up with as many different divergent ideas as possible, and then we compare those different ideas and approaches to our design specification, right? And that is by necessity a culling of ideas, right? I can't use magnetic levitation. I can't afford it. It's going to go away, and that becomes a convergence to a narrower solution that leads to the detail design phase. [A]

All participants described the iterative nature of design and the importance of ongoing testing or verification of concepts or designs, and diagrams drawn by participants tended to circle back on themselves. Most indicated that a designer could move between steps or backtrack as necessary. As one explained, looping back and forth is normal and continues throughout the design process (Fig. 4a):

> You go back and get a little more information and you refine and you go back and get a little more information. Sometimes you get to a spot and you go, 'Oh, damn,' and you've got to go all the way back or…two-thirds of the way back to where you were. [B]

She further explained that typically these returns through the process stages happen frequently at the beginning of the design process, resulting in large amounts of additional research, problem framing, and design, but naturally become smaller towards the end of the timeframe, as designers focus on one final problem definition and solution (Fig. 4b).

Several discussed the need for smaller loops within the larger cycle: "It's the same process within the process. It's like a Russian doll of design thinking, right, but you have to go through in big scale and little scale in almost every step of the way" *[A].* One indicated that designers might jump from one activity to another in all different directions, reflected in her sketched vision of the design process; "I should take 'start' out, because there's not

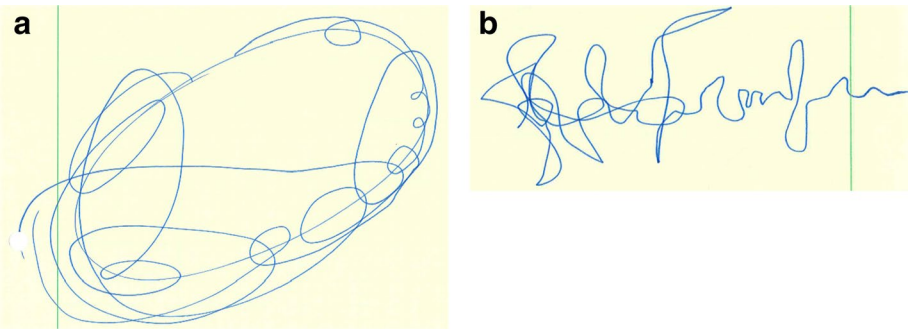

Fig. 4 **a** Designer loops back again and again through the process. b. Loops and changes become smaller as the design process nears completion [B]

really a start or a finish, although play and explore is kind of a good place to start" (Fig. 2; [H]). Another stressed that the process was not only cyclical, but entirely non-linear, as multiple stages might occur concurrently, "like the five stages of grief" *[E].*

Participants also discussed the role of prototypes, with most of these stressing the importance of low-cost prototypes that can be used early in the design process allowing for quick feedback. Two discussed the use of modeling (e.g., CAD, mathematical modeling) or prototyping of subcomponents where it would be too expensive or time-consuming to prototype the complete design. While most participants indicated that prototypes were useful for gathering user feedback, others stressed the value in testing whether the prototype or model met technical requirements. One explained that a prototype could also be used to "externalize cognition," testing out one's own thoughts about what they are designing *[G].*

How are definitions of design activated in a transdisciplinary educational context?

In this section, we will discuss how participants taught design within this transdisciplinary program. As discussed in the first sub-section, it became clear that no-one had purposefully provided a definition of design for the students, which was seen as a purposeful move by some and an oversight by others. In the second sub-section, we discuss the design models presented to students, and how these were presented by faculty. In the third sub-section, we will describe areas of particular focus stressed by participants. Finally, we will discuss faculty members' intended use of prototypes as an integrated part of the design process, and particular challenges faced in encouraging students to use prototypes in this program.

Defining design: Who, when, and how?

Based on our interviews, we are uncertain whether any faculty teaching in the program had explicitly defined design or design process for transdisciplinary students. Most participants indicated that they did not present a definition or description of these terms. However they assumed someone else had done so. Two participants with the most experience with studio teaching indicated that they intentionally did not define design. Rather, they began by referring to students as "designers" who are in a "design class," encouraging students to enculturate into a studio culture, and allowing them to iteratively develop their own definitions of design. Another emphasized that "We've role modeled, we've enacted and we've expected of students designerly practices. Design practices and thinking and components that are commonly associated with design" *[G].* Most agreed that student experiences should focus more on the process and problem than solutions or tangible outcomes. Participants also highlighted that they were guided by theoretical principles and constraints, the responsibility of designers to change and bring something new into the world, and focusing on the needs of users. However, it was unclear how consistently these elements related back to their personal view of design.

Presenting design models

Most participants had a preferred design model that they thought should be taught in the transdisciplinary program. Models varied in number and name of steps, the degree to which one could back-track or take steps out of order, the role of research and user data, and the level of divergence to be expected across disciplines or purposes. One participant indicated that there are many models that can be used for specific purposes, but do not

have to be followed directly. He described what he referred to as an "anti-process" he uses when teaching introductory design courses, "which is explicitly trying to not articulate a design process" *[F].* In this model, students are directed to spend roughly 50% of the time at any point in the design process on research to find new information, while the remaining 50% would be spent "trying to apply that information, doing something with it and making stuff":

> We talked about it in class explicitly as the co-evolution of problem and solution—that's what's happening. They're re-understanding the problem anew and because of that re-understanding of the problem they're going to generate different solutions, and as they generate a solution, they're going to generate a new understanding of the problem. This always happens, it's a back and forth, it's why it's a 50/50 basically. [F]

Another participant said that he selects the model for teaching based on the tendency and needs of students:

> For my theater students it's actually less about empathy because [they] kind of already get that but [need to focus on] iteration and planning and process. Our [transdisciplinary] students tend to already want to do this like this straight line thing and so I find myself with them trying to get them to do this sort of looping, less rectilinear kind of thinking. [A]

Although when sketching the process as part of the interview he created a flow-chart-like block model (Fig. 3b), this participant deliberately found images that better portrayed the "messiness" of design to hang up in the classroom:

> The drawing, this less linear drawing, it was more useful because of, the ones that I used, when I pulled it up, I printed out and posted up were roughly circular but had, I mean the company that drew them deliberately pulled out the nodes and did these weird amorphous amoeba-like shapes so that it wasn't…It didn't look like a cycle. It looked like a weird pathway through the woods. [A]

Despite the variation in models described, several participants expressed a firm belief that the entire team used the same process in their teaching. When asked what this process was, one stated "*we do the pretty common one*" *[C].* Another gave a more nuanced answer, stating "*we're reasonably unified on design as a whole and general steps to go through, the way information influences it, the way the user needs to influence it,*" but then recognized that different individuals likely used different jargon which may have impacted implementation [B]. While underlying beliefs about design were not highly misaligned, it was surprising to note that a number of instructors were not aware of students' exposure to different approaches each semester, and these issues had not been explicitly discussed with students.

Focus of design instruction

In addition to describing the process they provided students to use in class, participants discussed aspects of design they focused on in their teaching. One of the most commonly discussed aspects was the importance of focusing on the problem rather than the solution, which was sometimes a struggle since students tended to be solution- or technology-focused

and often preferred hands-on work. Participants emphasized the importance of conscious problem framing as a core part of engaging in design:

> [Students] find a problem formulation and they stick with it…, although sometimes they didn't realize they were selecting it. Whereas, an experienced designer would see the selection of the problem in the framing and scoping of the problem almost as equal weight with the creation of the final thing, they view it as this cursory, we must do this thing, but they very much minimize its role. [F]

Participants also indicated that students had a tendency to design things they were interested in, without determining whether there is a need. "[Design should have] some sort of real need attached to it. [Transdisciplinary students are] light on the real need attached to it part, more on the, it's a thing that exists and because it exists it is a design" *[F].* Two instructors stressed that students should learn to examine their own perspective and how it impacts how they see problems and solutions. "We want them to…show us they understand or have a point of view, building a perspective. This is the difference to be between transdisciplinary and multidisciplinary is doing those meaning making activities" *[G].* Another reminisced about several conversations she had with other instructors who had taught students with different backgrounds, and concluded that technology and engineering focused individuals (including herself and the students) tended to be too focused on developing physical solutions:

> It's at the center of the way that I think about creative activity. And so how do we move students… well, should we be moving students beyond this object physically centered notion of design? And if so, how do we do that? I think if we really want to do that, and I think there's some very strong benefits to doing that. And some of it's just sort of inherent and one of those things that I come back to with my engineering degree, how you think about a process and a problem and how you frame the world and how you go about doing what you do. It's part of the reason I'm a hyper linear, hyper logical person. So much of that comes through how you learn whatever it is you choose to learn in your life. [B]

She then reflected that having students build things during the first semester might have been a mistake:

> On a very concrete side, first semester needs to not be about build something. And first semester was very much all about learning how to build things with this first cohort [….] I think the earlier you have them building in a space that they associate as a design space, the more concrete that becomes how they think about design. And so maybe those first couple of semesters are more about the low fidelity prototyping and the wire framing and the story boarding as design, rather than trying to introduce that later. And I think we had some of those observations that we did some of those things backwards. [B]

All participants discussed the importance of research within and informing the design process. Multiple types of data sources were mentioned. Some participants focused on use of existing secondary resources to understand a user group or context.

Two participants suggested research on materials and budget. "You have to research the materials that you're going to use…Let's say you're interested in something being sustainable for the environment, so you have to research where are you going to get those items that you need" *[E].* Only one participant suggested reviewing existing designs (i.e., precedent), suggesting that students should "look at past data on how

people tried to maybe work with the issue, come up with maybe new things both on the research they've done, examine those" *[C].*

All but one participant stressed the need to conduct user research. "You have to research who your users are, what their needs are, what their constraints are. You have to take into consideration what means they have available to them, access" *[E].* This proved to be particularly difficult for students. When required to do so, students tended to shy away from finding authentic potential users to interview or conduct usability testing with, preferring to use their peers. Students needed guidance to not only collect data on users, but also to empathize with users' needs and describe how these related to a larger context:

> You're designing number one for a user and number 2, you need to be aware of the context in which that user exists in. We spoke very much in terms of gender and society and culture and economics, but that was the biggest push [D].

Empathizing with users would also entail understanding how and why they would intact with the design. As one explained, students "have to take into consideration who your users are, take into consideration the necessity of what it is that you're creating. What makes it necessary? What makes it better? What gives it purpose? Why is it a matter of consequence?" *[E].*

Despite these efforts, it was an instructional challenge to help students understand the need to focus on user's perspectives. One instructor explained that once students had improved their interviewing skills, they still did not apply what they had learned to being user-centered. "They do reasonably good interviews, insightful interviews. Interview is done, okay, now I'm designing what I want to design" *[G].* Faculty tried a number of approaches to not only provide access to information about users, but to further help students empathize with them. Although they had some successes, several reminisced about what they considered failures.

> We had a professor from communication come in [when introducing a design project related to] building toilets for India and then seeing if they functioned and if they were used. […] She gave plenty of […] explicit examples of if you don't have a lockable door, it's not a good place for women to go. If you put a roof on it, it's going to be used for grain storage. This is just one example of you need to be aware of flooding in the areas, you need to have it elevated in some way. One example to where you're looking at your users and you're using that information for very specific design principles on your toilet [….] I have to admit I don't think that they got it. There's something there that was amiss. I don't know if I can very, very eloquently articulate what it was, but there was something that they didn't quite get. [D]

Another reminisced on the experience of her mother, a retired school teacher who came in as an expert on education to talk with a student developing educational game. The student spent a portion of the interview time attempting to convince this expert of the importance of games in education, reducing the amount of time spent asking open questions about her experience with children.

> My mom […] kept desperately trying to get him to make the connection with the experience he was in at the time, and he couldn't do it. She kept trying to draw it back to certainly what she knew of the program, the transdisciplinary program, based on my input to her and what they were doing. Weird disconnect intersection kinds of places where they… again, can't or won't let them come together. And so, yeah,

> I would absolutely tell you I would expect that that student would not say that that process is a design process, which is a little scary. [B]

Four participants discussed how the concept of trade-offs was introduced—a theme for one of the semesters of instruction under study—in part to help students move away from a focus on finding the correct or "good" solution:

> For spring we introduced design with the lens of trade-offs. The idea is you're designing something, but you're not getting the perfect solution per say…You're designing in a certain context. What happens when you do one thing, it might take away from another thing. Good and bad is a meaningless term, it's really what is the effect and why are you making the decision you're making. Why is thing A more or less important than thing B? Again, trying to give them different lenses to that process of design. [D]

Prototypes as a mean of representing design ideas

Finally, all instructors discussed the use of prototypes as part of engaging in design activity. The majority stressed the importance of low-fidelity prototypes used early and frequently in the process for quick feedback; however, participants generally felt that encouraging students to create early, simple prototypes had been a challenge. Two participants in mentioned students' frustration with sketching and low-fidelity prototypes in particular.

> Fascinating, the student reactions to paper prototyping. One student actually used the word "kindergarten tools"…. If they aren't physically building two-scale or in lumber or metal or something then it's somehow it's perceived as less valuable or less useful. [B]

Participants indicated that they stressed to students the value of prototyping early and often, but noted that students were uncomfortable with that part of doing design work. As one explained, students had a tendency to continue to seek information about technical feasibility of materials in the abstract, while hesitating to actually create a prototype using the materials available:

> Generally, it's like fear of failure. [I tell them] just build it. If it breaks, you spend like $20 worth of lumber. It's like, "I don't really care. You learned something from it. I would like to see more of it." I would like to see them train through four prototypes this semester, like four iterations. (Figure 5; [C])

Participants mentioned their belief that prototypes had the potential to serve multiple purposes. All but one instructor focused on the use of prototypes as part of user testing, while some also discussed the use of prototypes to determine the correct materials and feasibility of the design. One explained how repeated prototype-testing loops could help refine understanding of the problem (Fig. 5):

> I think they should always [prototype], as they make the iterations; they'll probably go all the way back to the very beginning of identifying the problem again. When they get to a certain headache, they're like, "This isn't fixing the problem," but through this project we discovered that's not actually the real issue. [C]

Two participants in particular discussed how the use of prototypes also allowed students to externalize and question their own thoughts about their design, a theme that was implicit

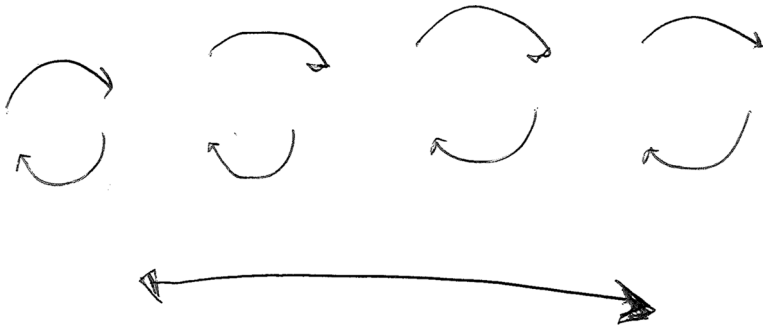

Fig. 5 Repeated rounds of prototype testing and revising problem framing [C]

in many of the interviews. One explained, "There's this commitment to user research, but user research isn't different from making stuff, you can make stuff and then use it to talk with users more—that's the essence of reflective design" *[F].* Another explained,

> I think prototypes can be hugely useful in externalizing cognition…. Our students don't seem to like to externalize cognition. They were very resistant to show us stuff. And we were, we want to see, want to help, we want to use this as a thing we can discuss about…. If I'm designing a bowl, does this work as a bowl? What is this telling me about my understanding of what a bowl is? [G]

Three participants discussed the need for students to consider time and resources constraints, requiring the use of modeling or sub-component prototypes. Use of structural analysis, CAD, and other modeling techniques were discussed. Component or partial prototypes were thus more appropriate in some contexts. For example:

> If you're building a slide you may want to prototype and user test types of materials for how they feel. You may want to say 'Okay, I'm just going to build something that doesn't look like a slide, but it's going to use plastic, and one's going to be metal.' You may think in those terms about components, or 'What kind of steps do I want to build?' You maybe build a set of wooden stairs, or stairs that are thicker or thinner and have people walk on them and see how they feel. The various components of the product. [H]

In all, while participants were reasonably aligned in regard to the importance of prototyping, this commitment did not generally result in prototype-rich activity on the part of students. This may relate to differing conceptions of design shared by participants and used to inform instructional strategies, but these potential links are difficult to fully analyze and explicate.

Discussion

In this study, we have identified conceptions of design across multiple transdisciplinary faculty, their approaches to teaching design within a transdisciplinary program with a studio component, and the potential barriers to alignment in pedagogical implementation. These faculty struggled to identify and implement design-related pedagogy, revealing lack

of full agreement regarding what design *is* and how they feel design should be activated in a learning environment. These findings indicate the need to interrogate differing disciplinary expectations, which may impact one's conceptions of design and the activation of those conceptions in a studio learning environment. In this discussion, we specifically call attention to the need for instructional alignment around design activity and the impact of this awareness on broader shifts towards design-focused curricula in emerging design disciplines.

Instructional alignment when viewing design as transdisciplinary

Although there are similarities in the way participants viewed design and the design process, there were also significant differences. Participants each drew from their own disciplinary perspective(s) as they taught in an integrated studio environment. However, few of the participants coming from a humanities background had prior experience engaging in studio instruction, and at least at first, they did not tend to identify themselves as being design educators. In the learning environment created each semester, faculty co-taught with others that had different disciplinary backgrounds, and over time, this co-teaching did seem to allow definitions of design to converge, albeit generally in a tacit manner. Even those experienced in certain forms of design activity came from a variety of different disciplinary and studio traditions (cf., Brandt et al. 2013), and these participants generally had different disciplinary expectations regarding how humanities perspectives might be brought to bear in the teaching of design.

The participants' lack of awareness of the differences in approach—particularly early in their transdisciplinary teaching experience—indicates that conceptual alignment may be an important area to explore when engaging in multi-disciplinary learning environments. Although some of these discussions can and should occur as early as possible in the design phase of program design, the types of discrepancies we identified were not obvious during initial discussions. Furthermore, faculty themselves changed their views over time spent co-teaching in the program. Check-in meetings and even debriefs about "how it's going" were not sufficient to illuminate the sometimes subtle but important differences in underlying conceptions of what design is and how it should best be taught. This highlights the importance of purposeful discussions as part of periodic program meetings or retreat which engage all faculty and staff and ensure that everyone's voice be heard in order to ensure mutual understanding as well as buy in. It is also important to determine both up-front and on an ongoing basis at what level curricular and pedagogical decisions are made. In our case, the initial proposal included design as a program-level element (Exter et al. 2015). However, many decisions were made on a semester-by-semester basis by co-instructors. There was little decision about planning for instruction across a multi-year curriculum, up to and including determining when or whether students would be given a definition of "design," or which process model(s) would be introduced when. This may, in part, be due to an institutional history of faculty autonomy which contrasted with our desire for a coherent program design.

Finally, although exposure to a range of design problems, contexts, users, and design "flavors" is valuable to students, we suggest that without recognition of this diversity, the work of developing and crystallizing shared definitions is often seen as unnecessary or distracting. Students can be cast in the role of translator—expected to bridge differing understandings of design—while faculty are not performing this translational work due to their own lack of awareness. The shift in who "owns" or has responsibility for the translator role

has significant implications for curriculum design and pedagogy. Ultimately, it does appear that design—in its transdisciplinary form—is a fertile ground for the kinds of integrated instruction planned for the program, but requires management both on conceptual and instructional levels to be successful. Future work should address the unique instructional implications of teaching designers across disciplinary modes, including the belief systems of instructors and the impact of these beliefs on studio practices.

Design as a disciplinary quality

Considering the lack of alignment in the conceptions of design across the program faculty, the broader lack of consensus regarding epistemological stances across engineering disciplines in relation to design (cf., de Figueiredo 2008; Dym et al. 2005) or design pedagogy (Schön 1995; Atman et al. 2007; Crismond and Adams 2012), seems unsurprising. Recent efforts to foster educational experiences that cross disciplinary boundaries create new opportunities to synthesize unique pedagogical and disciplinary approaches. Such experiences provide students tools to understand and tackle complex global challenges in ways that would be impossible within siloed disciplinary coursework. The transdisciplinary concept of design, as both an epistemology and way of acting, has proven to be one effective means of facilitating this connective process (e.g., Cross 2007; Dorst 2011; Krippendorf 2005). However, cultural and institutional barriers make it difficult to introduce these types of integrated learning experiences in disciplines traditionally reliant on very different pedagogical approaches. Understanding how teaching faculty of differing backgrounds translate conceptions of design into pedagogical action therefore has substantial value for the engineering design community, both clarifying the role and extent of design conceptions, and the impact of these conceptions on the teaching and learning of engineering.

In this program, faculty were not at a great conceptual distance from one another, but the gap that remained was still substantial—particularly when translated into the signature pedagogy of the studio. For instance, disciplinary structures implicit in prototyping and research tended to take on specific disciplinary forms, with participants often unable to effectively bridge across their multiplicity of experiences to present a united, transdisciplinary front to students. Ultimately, as these faculty members attempted to teach students to take on a transdisciplinary identity, we found that the members of the instructional team had to engage in transdisciplinary identity work themselves, in order to coordinate their vocabulary regarding design and its role in studio practice. As we continue to build a space for inter-/multi- and trans-disciplinary programs that bridge across current knowledge siloes, we acknowledge the value of design as a bridging discipline, but also note the challenges of building a unified vocabulary, epistemology, and set of pedagogical practices. Future research should address the nature of design itself as a trans- or inter-discipline, and the impact of this changing disciplinary status on various studio practices such as critique, research, and prototyping.

Furthermore, although there is a long history of interdisciplinary education within design programs as well as in liberal arts, the number of novel inter-/transdisciplinary programs is on the rise. This is evidence by the current popularity of alternative forms of instruction, as well as increased interest in a larger range of types and levels of interdisciplinarity (Ashby and Exter 2019). This article focuses on one particular and rather unique transdisciplinary program, which integrates liberal arts, design, and technology education. Future research is warranted on the nature, benefits, and challenges of alternative interdisciplinary programs that combine design with other approaches.

Conclusion

In this paper, we have described the conceptions of design articulated by faculty in an undergraduate transdisciplinary degree program, and the impact of these conceptions on their interactions within a studio learning environment. While we did not identify characteristic differences among faculty based solely on their disciplinary training, the range of beliefs and conceptions about design nevertheless led to a lack of alignment in many important areas that impacted the students' learning experience. The results from this study indicate the need to create program-level alignment in inter- and trans-disciplinary learning contexts, particularly in relation to philosophies of design engagement, process, outcomes, and the pedagogical or instructional elements that activate these beliefs. Further research into different approaches to do this, as well as the benefits and challenges of such approaches, is warrented.

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