# When World(view)s Collide:
# Contested Epistemologies and Ontologies in Transdisciplinary Education

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## Abstract
In conjunction with the drive towards human-centered design in engineering education, questions arise regarding how students build and engage a socially-aware engineering identity, and how this identity points towards beliefs about the nature of reality. In this paper, we describe how students in a transdisciplinary undergraduate program struggle to engage with ontological and epistemological perspectives that draw on this social turn, particularly in relation to human-centered engineering approaches and sociotechnical complexity. We use a critical qualitative meaning reconstruction approach to deeply analyze the meaning-making assumptions of the students. Our findings reveal characteristic barriers in engaging with other subjectivities, and related epistemological and ontological claims implicit in these subjectivities. Specifically, we show that students' observable behaviors often mask misalignments between their epistemic beliefs and the designerly practices they employ—failing to account for the multiple subjective realities that the tools are designed to uncover. For these students, that misalignment makes the learning or practice of designerly behaviors less formative of a designerly identity. We conclude with implications for encouraging socially-aware identity formation in engineering education.

## 1. Introduction
Increasingly, engineers engage with challenges that are characterized by complicated social elements related to technological development and adoption that make the challenges "wicked" in nature [1,2,3]. Such challenges, at the core of requirements for the Engineer of 2020 [4], require engineers to adopt and exploit multiple disciplinary perspectives, identities, and ways of thinking and acting (e.g., [3,4]). In parallel with more technical engineering activity, engineering education is increasingly concerned with preparing the next generation of engineers to engage with problems in socio-technical contexts (e.g., [5]). Such sociotechnical problem solving relies not only on technical skills but also on problem framing and other sense-making activities that enable the creation of a richer understanding of design problems [1,2,6].

Engaging with the sociotechnical underpinnings of engineering practice also interacts with students' internalized conceptions of reality and truth as well as their implicit and explicit epistemological perspectives. The "social turn"—a shift to more socially connected engineering practices—in engineering and engineering education has resulted in new pedagogical practices that encourage students to develop multiple literacies that extend beyond content knowledge (e.g., [7]). These capabilities are grounded, in part, by a deep understanding of users' needs, an ability to articulate sociotechnical and cultural boundaries [8], and the competence to make sense of those boundaries within and across different contexts. This traversal of sociotechnical boundaries includes instances when the user's needs and boundaries conflict with students' existing worldviews or ways of making sense of the world (e.g., [9]).

Previous research has suggested that for engineering educators to engage in this social turn, engineering itself must become more human-centered [10] and more inclusive. Thus this social turn seeks to shift students' focus from designing *for*, with a mechanical or contractual circumscription of engineering activity, to designing *with*, highlighting the human and social qualities of engineering activity (e.g., [10-12]). However, scholarship related to this turn has rarely addressed the underlying epistemological structures and related views on reality that undergird students' operationalization of human-centered design skill. We argue that differing epistemological views construct different foundations for how students develop, conceive of, and employ human-centered approaches in their work.

In this paper, we continue the conversation on humanistic and socially-oriented engineering activity by exploring how students struggle to engage with designerly behaviors that rely upon both technical skill and social awareness to construct conceptions of reality for design projects (e.g., [13,14]). Specifically, we describe how students in a transdisciplinary undergraduate program conceived of barriers to transdisciplinary thinking and action, including the role of information and user research. We identify the identification, acquisition, and activation of multiple disciplinary and interpersonal identities which often conflict. We explore these conflicts through the lens of epistemological and ontological assumptions using a critical qualitative meaning reconstruction approach, revealing how students developed their own humanistically-informed engineering identity and struggled to engage with disciplinary or designerly ontologies. The vignettes we analyze below demonstrate that the performance or use of user-centered approaches or methods does not, it itself, shift student's underlying beliefs or ontological position. In our synthesis of these vignettes, we will show that the formation of a designerly identity—tied up with one's epistemological and ontological stance—requires additional cognitive and intersubjective ability beyond only the learning or practice of designerly behaviors.

## 2. Purpose

Our purpose is to explicate the epistemological bases and ontological viewpoints that students activate when engaging in engineering activity. In this paper, we address the alignment of these viewpoints with epistemic assumptions regarding the nature of design thinking activity, and the cognitive flexibility or inflexibility of students when viewpoints and assumptions are mismatched. We explore these ideas in the context of students' learning and practice of user-centered design alongside their acquisition of disciplinary engineering knowledge. This exploration occurred longitudinally as students learned to act in designerly ways in a transdisciplinary classroom. We specifically target students' epistemologies and ontologies because they demonstrate how students conceptualize and internalize disciplinary knowledge, including their beliefs about design and the role of both designers and users in design activity.

## 3. Background

### *3.1. Epistemologies, ontologies, and Habermas' three formal worlds*

At the heart of this study is a discussion of the meaning-making approaches students use to make sense of the world in which they perform design, and how this meaning-making relates to students' understanding of the epistemologies and ontologies that undergird their experience. We rely on Nelson and Stolterman's [15] understanding of how epistemologies and ontologies are intertwined in design praxis, where an ontology is the nature of being or what makes something "real" to us, and an epistemology is a way of thinking about or engaging with that reality. Within this framing, an ontology emerges as we engage in design activity, and an epistemology relates to the underlying framing through which students know, think, and reflect upon that design activity as a form of praxis. More broadly in the philosophy and engineering literature, epistemologies address how an individual perceives knowledge and its general scope [16], "[providing] philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure that they are both adequate and legitimate" (Maynard, 1994 cited in [16]). For the purpose of this study, our discussion of epistemologies refers to the basis on which students' knowledge sits, which we refer to as their *epistemological stance*. That stance provides an explanation for how students conceptualize the world at an individual level in terms of how reality 'works,' but necessarily relies upon a deeper understanding of what constitutes reality, or one's ontology. Taken together, these elements form one's *worldview*.

To make sense of these epistemological and ontological perspectives, we also rely upon the work of second-wave critical theorist Jürgen Habermas in articulating how we communicate in relation to our social reality. According to Habermas, communicative acts become *rational* as they relate to three "formal worlds": the objective, subjective, and normative (Table 1; [17-19]). It is through the fusion of these three formal worlds that our reality (i.e., ontology) and way of reconciling and making sense of that reality (i.e., epistemology) emerge.

*Table 1.* Habermas' Three Formal Worlds (adapted from [17-19]).

| **Formal World** | **Definition** |
|---|---|
| Objective | The objective world (or "the" world, implying the singular) is accessible to multiple individuals, whereby a phenomenon may be judged for what it is or what it appears to be by multiple subjects. Validity disagreements within this world are resolved through mutually agreed upon standards of truth and efficacy. This world is most frequently addressed through post-positivist theoretical perspectives and scientific paradigms. |
| Subjective | The subjective world (or "my" world, implying the individual) has limited access for those outside of the subject's experience, and cannot be fully known by any other individual. Validity disagreements within this world are resolved through external standards of criticism. This world is most frequently addressed through phenomenological or identity perspectives. |
| Normative | The normative (also normative-evaluative) world (or "our" world) deals with our social reality, and includes claims about what should or ought to be. Validity disagreements within this world are resolved by engaging with the "rightness" of norms or actions. This world is most frequently addressed through critical or socially-oriented theoretical perspectives. |

These three formal worlds fuse together as we communicate. These worlds individually and jointly have meaning due to the intersubjective space that forms among multiple human actors across a fusion of these worlds. This intersubjective space refers to the potential for meaning making and mutual understanding that occurs when two individuals communicate. This space acknowledges that language is always already subjective yet also social, requiring each actor to build their understanding of a communicative act through a fused set of validity claims originating from each of the three formal worlds. Intersubjectivity is achieved as a limit case when mutual understanding is achieved. This assumption of *mutual understanding* implicit in an intersubjective space requires human actors to take on all three subject positions assumed in the three formal worlds (i.e., the subjective "I," the normative assumption of what ought to be implicit in "we," and the objective and externalized sense of the "me") as they make meaning from observations and experiences. The degree to which an intersubjective space might be successful and communicative is contingent on the validity claims which allow each formal world to be "true" (which Habermas refers to as a form of internal rationality), agreed upon by the human actors (c.f., Habermas' *ideal speech situation*; [20]).

We use these understandings of reality and the ways our communicative acts reveal and interplay with this reality in this paper, and include a fuller explanation of our methodological and theoretical commitments in the methods section.

### *3.2. Identities in design and engineering education work*

We are driven in part by questions of how students transform into "[d]esignerly ways of knowing, thinking, and acting" (e.g., [21])—what we term as one's *designerly identity*. Because ontologies underpin the development of design ability (c.f., [22,23]), identifying and teaching in relation to these evolving or transitioning ontologies may enable student development that treats identity formation as peer to the acquisition of disciplinary content.

Existing scholarship includes discussions of what professional designerly identities look like and how those identities develop in students, including studies of expert or experienced designers in practice (e.g., [3,24]). As an example, Daly et al. [24] discuss six lenses of how professionals have come to understand design, including: personal synthesis, directed creative exploration, and organized (cross-disciplinary) translation. They discuss how those experiences and developments allow for the formation of one's designerly identity. Other work looks at the underlying components of thinking that drive expert designerly identities [21,23]. In general, these studies attempt to describe either the processes, the tools, the heuristics, or even the underlying logical basis for the creation and sustainment of an expert designerly identity [25]. While Dorst [25] proposes that an expert design identity is based on strong indications of a progression from objective to subjective to intersubjective ways of viewing the world, the actual origin of these epistemological bases is left implicit and underdetermined.

In educational research, studies tend to focus on how students develop designerly identities as they progress towards more expert design performances (e.g., [10]). This includes work by Crismond and Adams [22] which looks at how heuristics used by students are analogous to those used by experts. Crismond and Adams identify an intermediate stage between novice and expert of the "informed designer." While, again, not discussed in the context of epistemological beliefs about reality itself, they do address the influence of epistemic beliefs on the field of design, and of designerly knowledge and identities in general. Zoltowski et al. [10] look at the experiences students have when engaging in human-centered design. They conclude with seven distinct ways that students experience or internalize human-centered design. Some of their observations have ontological implications (e.g., 'designing for others') or imply epistemological perspectives in students (e.g., ‘user as information source input to a linear process’).

However, researchers have not expanded the concept of designerly identities in students to explore those underlying epistemologies and the ways these epistemologies impact the formation and sustainment of identity commitments. Different epistemologies of knowledge are implicit in the two examples above; however, an understanding how the progression of ability, or of designerly role, integrates with change, or lack thereof, in the nature of reality that students use to ground their design work is lacking. It is unknown whether the informed designer [22] has experienced an epistemological shift, or whether the lack of such a shift explains the difference in implementation of similar heuristics by informed designers and experts. Similarly, the varying ontological roles at play in Zoltowski et al [10] suggest that students’ beliefs about their role, which are heavily related to the forms of knowledge the student feels are valid or appropriate, influence the way students make meaning.

The unspoken nature of epistemic and ontological components of identity formation is not limited to designerly identities—it also appears in broader engineering education research. While work on formation of engineering identities abounds, the focus of such work often engaged with implicit assumptions about how engineers view the world (e.g., [26, 27, 28]). Such research includes a focus on progression towards graduation of students who do not fit normative engineering identities (e.g., in terms of race, ethnicity, gender) [26]. Other work looks at how students do or do not attach themselves to normative identities of engineering, and certain epistemological subcomponents (e.g., math or physics identity) of those identities (e.g., [29]). Such work is invaluable to understanding and creating change in engineering education, but opportunities for deeper understanding exist in looking at how these experiences change students’ underlying views of knowledge, reality, and the world. For example, Godwin et al. [28] assess students’ beliefs about their abilities to perform in math and science, which they connect to engineering identities. In this case, connections to underlying world views about knowledge are exchanged for a focus on connections to the normative identity that students are presented with to establish belonging.

When researchers that are engaged in these discussions reference epistemologies, they often do so in ways that are highly implicit, resulting in untested assumptions about the underlying objective or subjective world views that ground ways of thinking and viewing the world. Much of the work on engineering identity is framed by a discussion of epistemologies, commonly drawing on Figueiredo [30]. Figueiredo identifies four components of an engineering epistemology: the engineer as sociologist, scientist, designer, and doer. The defined epistemology in this case is constructed largely through the attachment of an engineering identity to other identities (e.g., ‘scientist’). Each relationship between identities carries with it ontological and epistemological assumptions of its own. Drilling down to objective and subjective epistemological beliefs and associated ontologies does not occur explicitly—but the underlying concepts are apparent in references to fields commonly identified with objective world views (e.g., the scientist) and subjective world views (e.g., the sociologist).

## 4. Method

In this paper we employ dialogical meaning construction to explore students’ epistemological and ontological assumptions. The meaning reconstruction approach is based on Carspecken’s [17] critical qualitative methodology, which is informed by the second-wave critical theory perspectives of Jürgen Habermas, Giddens' speech-act theory, and the inferential semantics of Robert Brandom among others. The study occurred within a broader project that tracked the development of an experimental, design-centric, transdisciplinary undergraduate program within a college of technology at a research-intensive university. A critical theoretical perspective informed our research approach throughout the data collection and analysis over the multi-year ethnographic project. Data collected for the project included classroom observations, interviews, focus groups, and artifacts created by students and faculty. In the sections below, we describe the study context and method in more detail.

### *4.1. Theoretical perspective*

In this paper we adopt a critical theoretical perspective. We focus on how students build identities as designers and transdisciplinary thinkers and how that identity construction takes place within a transdisciplinary educational program. Critical research in the education community frequently focuses on underrepresented minorities, including methodological grounding in feminist standpoint theory and critical race theory, among others [31]. However, a critical perspective drawing on pragmatist philosophy and critical theory can also be applied more generally to the ways in which meaning is made and negotiated on individual, institutional, and societal levels. This use of criticality focuses on the implicit beliefs of individuals, and the acting out of these beliefs that play a role in forming normative and objective realities. In this paper, we use that critical stance to interpret the implicit epistemological assumptions of the researchers and instructors engaged in the program under study—interrogating the relatively simplistic assumptions that have historically been made about students' development of epistemological awareness.

The critical theoretical perspective we use in our data collection and analysis activities informs our focus in three important ways. First, while criticality has been most commonly deployed in engineering education research to look at issues of equity, justice, diversity, and inclusion, it can also be used to analyze any communicative or societal structures where interactions among the normative world and the objective or subjective world occurs. In this paper, we are focused on the normative dimensions of reality, which presuppose ontologies of designers, especially student designers, when they design. Second, we seek to more deeply understand how students operate across objective, subjective, intersubjective, and normative worlds, and how these worlds might indicate a progression of meaning-making ability in a design context. This perspective contrasts with typical developmental models that conflate students' growth in content knowledge with students moving from objective, to subjective, to intersubjective ways of seeing reality. Finally, student and faculty speech acts are heavily influenced by institutional context, personal understanding of a topic, and each actor's own lived experience. Because these elements are highly contextual, it is important to understand all reasonable *and* potential meanings of a student's speech acts. While some scholars might refer to this deconstruction as post-structuralist [32], we undertake this process through a critical-structuralist orientation because our purpose is to explore and critique assumptions that students experience a linear or immediate alignment of subjective, objective, and normative validity claims during the learning process.

### *4.2. Research context*

Data for this paper draws on a larger research project documenting teaching and learning practices during the development and implementation of an undergraduate transdisciplinary program. The program defines transdisciplinarity as a "unity of knowledge" that moves beyond disciplinary silos, including perspectives from the humanities that describe "disciplines and disciplinary work as essentially fragmented and incomplete" [33]. The degree program is offered within a more traditional College of Technology that includes majors such as mechanical and electrical engineering technology. Students are required to declare at least two focus areas; one technical focus area (e.g., mechanical engineering technology) and one humanities focus area (e.g., anthropology).

As part of the degree, students take courses from the transdisciplinary program, the larger College of Technology, and across the university. Students also enroll in a course taught by transdisciplinary program faculty every semester that accounts for 8 contact hours (4 credit hours). This course is taught using a set of overlapping studio and seminar pedagogical approaches designed to highlight the transdisciplinary nature of problems at the intersection of technology and society. The course is centered around broad problems that model the social turn and wicked problems that are common in engineering design problems. Typically, students work on both individual and team projects as part of the course while also engaging with texts (e.g., movies, research papers, etc.) from academic and non-academic literature that link to a broader understanding of a topic area. The courses are intended to introduce new learning opportunities while creating space for students to engage in synthesis of their other coursework.

Data collection within the program has been intentionally layered since the program's ideation stage. We collect multiple streams and multiple perspectives of data representing the experience shared by educators and students. Continuous data collection, educational research, and program assessment have been a core focus of the program since development began. In the broad project, data collection includes field notes (i.e., observational notes made of all class sessions by graduate students with entirely non-instructional roles in the program), video and audio recording of classes, interviews with faculty and students, and artifact collection and archiving. The artifact archiving includes both student and instructor artifacts that range from assignment briefs to students' submissions, to feedback on those submissions.

### *4.3. Data collection focus*

Our focus for this paper is on students' classroom activity during the fourth and fifth semesters of the program. In the transdisciplinary course taken during these semesters, students worked on a combination of individual and team design projects designed to elicit and reinforce human-centered design behaviors taught in previous semesters. In all projects, students were expected to engage directly with potential users through interviews, observation, and research. They then designed and built a series of prototypes which demonstrated their understanding of the users' needs, culminating in a working concept. Two instructors collaboratively designed and facilitated the fourth semester course while three instructors designed and facilitated the fifth semester course, with one instructor overlapping. Instructors included one with an engineering and entrepreneurship background (the 2nd author), one with a background in communication, one with a background in education and human-computer interaction (the 1st author), and one with a background in engineering and librarianship. The students used as examples in this paper had been enrolled for the previous three years. During the fifth semester, there were eight students actively enrolled in the program with seven of those students having been involved in all five semesters, and one new student.

For this paper we identified potential streams of insightful data beginning with interviews but engaged other data streams from the classroom experience when producing detailed meaning reconstructions of selected speech acts. Those data are presented in the results section in vignettes that stitch together the multiple data streams with the critical speech acts and rich descriptions of context. The findings section contains three vignettes that build upon these students' experiences across multiple semesters of the program. The vignettes include two individual examples, each involving an individual student, and a third example involving multiple students. We selected the examples to show specific examples of underlying epistemological beliefs and change over the course of the five semesters in the program in the collected data. Each vignette is centered around one participant respecting that each participants actions are grounded in their subjective worldview.

### *4.4. Analysis through meaning reconstruction*

To analyze the collected data, we utilize two techniques to facilitate meaning reconstruction in this paper: strip analysis and meaning fields. This approach draws on work by Carspecken [17], who has built a multi-stage critical ethnographic methodology focused on revealing explicit and tacit communicative assumptions in relation to institutional and social structures [18,19]. Broadly, the meaning reconstruction approach follows a recursive dialogical path which includes unpacking and documenting many potential meanings—bounded by the researchers understanding of the data within the context where it was generated and in relation to the specific actors. Once these meanings are articulated, the goal is not to understand the "true" meaning, but to recognize the communicative complexity inherent in these speech acts, and the implications of these meanings for validity and rationality in the social context. The overarching goal of this approach, and our use of it as a driving methodology, is to achieve "thick description, research transparency, disclosure, reflexivity, and sufficient explanation of method to allow an external entity access into the mindset of the researcher" [19, p. 329]. The remainder of this section includes a brief overview of the techniques employed in the paper.

The strip analysis and meaning field reconstruction techniques [19] allow for the researchers to iteratively identify and deconstruct vignettes from the multiple data streams through three phases; a data generation phase, a meaning reconstruction phase, and a dialogical phase. Because the methodology is recursive and highly iterative, it cannot be easily separated from the data. Throughout the semesters of study, we used strip analysis [34] as a way of forming and externalizing preliminary hypotheses regarding student behaviors, and then used subsequent observations and interviews to validate our understanding and build in points of data triangulation. Strip analysis is a means of foregrounding the reflexivity of the researcher, using emergent hypotheses or understandings of the social situation to identify and further explore potential research paths. This form of analysis relies upon extended engagement, validating or correcting initial hypotheses through further data collection and fieldwork. This approach allowed us to identify emergent themes regarding students' meaning-making approaches that were then further explored and elaborated on using meaning field reconstruction to highlight points of agreement, divergence, and ontological element(s) based on classroom role. The outcomes of these analytic steps also facilitate the creation of thick, multi-modal descriptions of events that demonstrate the researchers' reflexivity throughout the research process, allowing for multiple perspectives on the data. This approach is focused on revealing the researchers' process of interpretation, using transparency as a means of establishing rigor and trustworthiness.

The goal in constructing a meaning field is to include all possible and plausible meanings for a given communicative act, such that these meanings would be recognizable to the participants and are “meanings that other people in the setting might themselves infer, either overtly or tacitly” [17, p. 95]. The goal is to explore “a paradigmatic set of meaning possibilities” [19, p. 331]. These articulations of meaning possibilities are organized into relevant clusters, using logical statements such as “and,” “or,” “and/or,” and “or/and.” Our goal in the results section is not to explore and unpack each potential meaning. Instead, the meaning reconstruction process results in a potential set of meanings that we could explore as researchers and provides the reader with two specific useful affordances. First, this process explicitly demonstrates that our analysis details one of many potential meanings, rather than presenting and explaining one potential meaning in a way that implicitly privileges only that one. Second, it allows us to be transparent in how we are employing our critical theoretical perspective—selecting and deconstructing viable but specific potential meanings that align with the purpose of this manuscript.

### *4.5. Author positionality*

Because the authors have been heavily involved with the development and execution of the program, we believe a clear statement of our positionality and relationship to the program is important. For each author, we detail our professional background and our specific roles within the transdisciplinary program.

The lead author is an assistant professor of computer graphics technology. He has been involved with the program for four semesters in a combination of instructional and research roles including co-leading the research and evaluation team for the two years this study addresses. He co-taught the studio experience in the Spring 2016 (fourth) semester. He holds a doctorate in education (Instructional Systems Technology) as well as Master’s degrees in instructional design and graphic design. His research focuses on the role of student experience in informing a critical design pedagogy and how studio environments inform the development of design thinking. He is particularly interested in critique and professional identity formation.

The second author is an engineering education PhD candidate who focuses on entrepreneurship education research. He has been involved with the transdisciplinary program for one year in a primarily instructional role. He was a co-instructor of the fifth semester course that is a focus of this paper. His background includes a BS and MS in engineering, which he used as a startup founder and engineering design consultant. His research focuses on entrepreneurial cognition and measurement of complex cognition. Specifically, he focuses on characterizations and comparisons of expert and novice behavior through a critical analysis of personal epistemologies. He also studies inter-relationships between design and entrepreneurship as they apply to pedagogies that encourage sense-making and development of student identities.

## 5. Three Vignettes

To structure the results of our study, we present three vignettes using a reporting approach inspired by the critical incident technique [35]. Each vignette includes the perspective, speech act(s), and/or observations of one incident involving students in the program. As described earlier, all vignettes and meaning reconstructions were peer debriefed by five researchers who have conducted interviews and observations with these students over the past two years, increasing the validity of the record and allowing for increased confidence in our interpretations.

### *5.1. Integration of Educational Experiences Not Allowed*

The first vignette involved Paul. Paul is a high performing student with a disciplinary focus in mechanical engineering technology. He spent several formative years in a developing nation before attending a religious high school in the US. His professional interests involve helping underprivileged groups. The critical event occurred during Fall of 2016, while data for triangulation crosses multiple semesters before and after the event.

Instructors in the transdisciplinary learning experiences assumed that each student had at least two areas of disciplinary focus—one in a technology domain and another in a humanities domain. These areas of disciplinary focus were well known to the teaching faculty. The projects students completed necessitated students to use these outside perspectives, but avoided proscribing *how* they should or could be used.

During the fourth semester, Paul and other students worked on a water recovery device for a remote Pacific island as a semester long project. They iteratively identified approaches to adapt a solar still for the local environment. While there were significant mechanical and hydrologic components required to complete this project, the instructors provided only a minimal framework of resources (e.g., prototyping materials, conceptual advice) to encourage rapid prototyping across increasing levels of fidelity to identify and mitigate construction barriers. This just-in-time approach allowed students to take ownership of any disciplinary knowledge or additional learning that may have been necessary. This team only engaged in limited prototyping, despite suggestions for more levels of prototypes by the instructors.

At multiple points in the project, the students engaged with technical engineering activities, including assessing the lifespan of components, the pathways intended for water runoff, means of water collection and storage, and planning for typhoons or other storms that may disturb the still. No substantial efforts were undertaken to validate or model the design in detail. The instructors took a hands-off approach wherever possible, identifying potential challenges that needed to be solved without explicitly linking these challenges to specific content knowledge from other courses that the students may have taken.

This background contextualizes a specific speech act during the fifth semester that occurred in conversation with another instructor. When Paul was challenged by this instructor as to why he did not use knowledge from his mechanical engineering technology (MET) coursework to address problems encountered in a project that were germane to this knowledge, he countered:

> "I am not allowed to use that knowledge [from my disciplinary classes] in here."
> *(possible paraphrase, written down after the discussion had occurred)*

This paraphrase, in addition to later statements about disciplinary knowledge and Paul's use and conception of this knowledge across multiple semesters was used to construct a meaning field that demonstrates the range of possible meanings this act could have in the context of the transdisciplinary learning environment (Table 2).

*Table 2.* Meaning field of Paul's utterance.

| |
|---|
| [<u>possible psychological state: frustration</u>] |

Knowledge from one course is not allowed to be used in another class.
**OR/AND** My instructors have forbidden me from using knowledge from other courses in the transdisciplinary studies classroom.
**OR/AND** I must follow the requirements of the assignment verbatim.
**AND/OR** My instructors only want me to use knowledge from their own disciplinary areas.
**AND/OR** My instructors' disciplinary areas are easily defined and separate from my own.
**AND/OR** My educational experiences discourage me from thinking across multiple disciplinary perspectives.
**AND/OR** I only believe there is one "true" reality.
**OR/AND** I see relevance to knowledge obtained from other classroom experiences.
**AND/OR** Concepts from my mechanical engineering technology course are needed to complete my current project.
**AND/OR** Tools used in my mechanical engineering technology courses are not available in this class.
**AND/OR** The prototypes requested by my instructors are inconsistent with my MET course requirements.
**OR/AND** I see disciplinary perspectives as internally consistent but separate wholes.
**AND/OR** There are barriers between MET and design.
**AND/OR** My transdisciplinary classes are about design.
**AND/OR** The educational system does not encourage me to think of a unity of disciplinary perspectives and approaches (i.e., transdisciplinarity).

From these multiple clusters of meaning which may be read exclusively or as a composite of meanings, Paul appeared to be relying on a notion of disciplinarity that could be best understood as a set of *multiple objective realities*. This notion of multiple objective realities is represented in Figure 1 through the two alternative realities separated by a logical OR emanating from Paul's identity. Each discipline had its own rules and underlying ontology, but as these ontologies were raised to the surface and activated in an epistemic stance, Paul sensed conflict and raised a barrier to the integrative work that the transdisciplinary faculty not only allowed but encouraged by within the learning environment. Knowledge from multiple disciplines that was perceived to be in conflict—such as Paul's MET courses and design courses having differing meanings, and the differing goals of prototyping—presented such an ontological crisis that this student concluded that some external knowledge was simply ineligible for use.

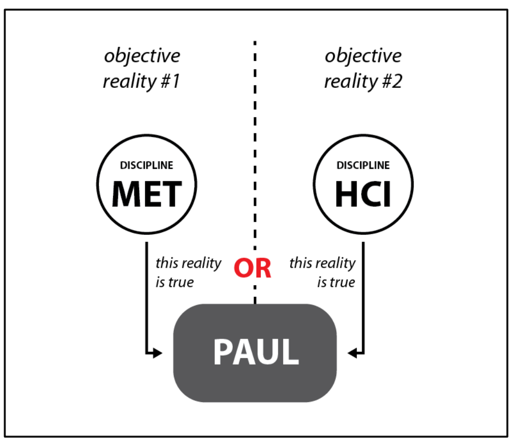


**Figure 1.** Paul's tension between two competing "objective" realities: that of his instructor (HCI) and that of his disciplinary focus (MET).

Paul saw the decision whether or not he could include a given disciplinary perspective in his coursework as an exclusive and binary decision. Based on the conversation which occurred after the primary quote, Paul's thinking was driven primarily by the disciplinary background of the instructor of the course being singularly 'allowable'. Either he could use the perceived monolithic disciplinary perspective of the instructor (labeled by Paul as "HCI" or "computer graphics") or he could use his main area of disciplinary focus: mechanical engineering technology. Since he perceived that the instructor had power over his grade and assumed that the instructor's goals are incompatible with his MET goals, Paul felt as if knowledge from his MET coursework was inadmissible and "not allowed."

### *5.2. Empathy Is Bounded by One's Worldview*

The second vignette occurred during the Fall 2016 semester and involved Ralph. Ralph has a disciplinary focus in computer graphics technology and education. He previously attended an 'unschooling' high school, and is an avid computer and board game enthusiast and intends to pursue educational game development professionally. As part of a user-centered design focus, students in the transdisciplinary learning experience were exposed to user research as a means of informing both the framing of a design problem and subsequent design decisions that narrowed that problem or validated a solution. To practice these user research skills, students were required to perform multiple interviews with individuals that they identified as part of a user or stakeholder during the research component of a two-semester individual project.

Based on his interest in game design and education, Ralph identified "serious games" as a project focus and chose to work on the design of a math-focused game for use in k-6 classrooms. Even though user/stakeholder interviews were required, he showed substantial discomfort about completing these interviews, stalling for multiple weeks despite instructor encouragement. Avoiding or putting off user-centered assignment components had been typical for Ralph, as well as some other students in previous semesters. Ralph was willing to interview or test with his peers in the course, but did not acknowledge the drawbacks of using college students as stand-ins for users in his actual user group. At one point during the semester, a course instructor's mother, who was a retired elementary school teacher, planned to visit and observe class. The instructor informed Ralph and offered her mother as a potential interviewee, provided her contact information, and offered guidance and reinforcement of the expectation. Ralph agreed in advance to conduct the interview on a specific class day, prepared a specific set of questions for the interview, and reviewed the questions with course instructors. During the day when the instructor's mother was present, Ralph was hesitant to begin the interview, and instead engaged in known patterns of avoidance: small-talk with other students, offering hugs to other students, talking with another student outside of the classroom, and fiddling with his watch and computer. These patterns of avoidance continued for almost 90 minutes of a 110 minute class period before one instructor strongly suggested that Ralph begin the interview, and he complied. Field notes from a research team observer details a portion of this interview experience:

> *[Context: Ralph is sitting on the couch, interviewing the instructor's mom. Writing with a mechanical pink pencil in his notebook that is lying down on the coffee table. He doesn't look comfortable, but he looks really engaged.]*

**Ralph:** **"Did you have an idea how many of the students you taught played games outside of the classroom, or even within the classroom?".**

**Interviewee:** "No, but, that's because of where things were when I left off (teaching) and where they are today. I was in a small girl's school, too…only two computers in the classroom."

**[He tells her that he is interested not only in video games but in board games and card games as well.]**

**Interviewee:** "Yeah, if you can make a game of something, for enjoyment, yeah!"

*[Researcher note: [Instructor's mother] goes on to talk to [Paul] about how instructional materials were totally different then and now on many different levels.]*

We used this conversation and Ralph's earlier behavior to construct a meaning field. The meaning field demonstrates the range of possible meanings that could be ascribed to Ralph's speech acts in relation to user-centered design, user research, and the role of interviewees in the design process (Table 3).

*Table 3.* Meaning field of Ralph's utterance, focusing primarily on the bolded portion of the observation notes.

| |
|---|
| <u>[possible psychological state: avoidant, nervous]</u> |
| I believe students should play games to enhance their learning. |
|   **AND/OR** Games can be digital or analog in format. |
|   **AND/OR** Games can be used inside or outside of the classroom. |
| **AND/OR** Everyone plays games (or they should). |
|   **AND/OR** She doesn't understand that everyone plays games so I should clarify the question. |
| **AND/OR** I believe the instructor's mom has been a teacher recently. |
|   **AND/OR** She is familiar with constructivist learning approaches such as serious gaming. |
|   **AND/OR** She values instructional/pedagogical approaches that I perceive to be modern. |
| **OR/AND** I think students have access to (digital) devices. |
|   **AND/OR** These devices should be used to play games. |
| **OR/AND** I conceptualize the purpose of interviews as a means of validating my own understanding of the design problem. |
|   **AND/OR** This teacher does not have experience in using games to promote learning. |
|   **OR/AND** I want the interviewee to focus on the problem I have identified on my terms. |

From these multiple clusters of meaning, we see Ralph's behaviors as circumscribing a set of assumptions about what constitutes "proper" interviewee-designer relations. While Ralph was hesitant to engage users or stakeholders in an interview setting, when he did, there was an underlying assumption that the users'/stakeholders' purpose is to validate *his* understanding of both the problem (i.e., unfulfilling or unrewarding K-12 educational experiences). This understanding contributed to his assumptions that the solution space (e.g., games as a motivational learning tool), was accurate and the interviewee *would* validate it. Ralph's assumptions are observable in his attempts to clarify his question when the interviewee's response did not validate his problem framing. While not only obliquely apparent in the transcript, we triangulate these assumptions with other data regarding Ralph's K-12 experiences that show a history of his desire for games to be more present in the learning environment.

While subtle in the example above, the manifestation of the assumed overlap was apparent throughout his project. Throughout other communication about Ralph's project, he consistently framed discussions using positivist language (e.g., "education is") rather than language that is indicative of subjective epistemology and individual experiences (e.g., "my experience in education is"). In doing so, Ralph repeatedly fused normative and objective worlds. This manifested further when Ralph worked with instructors to find scholarly research. He framed those conversations as needing to *support* rather than *inform* the project decisions he was making. When those pieces of information failed to materialize, Ralph struggled greatly. He felt his beliefs (i.e., his reality) was being undermined by the lack of scholarly information that supported his viewpoint. From Ralph's point of view, the lack of supporting research reinforced his view of a fundamental problem—rather than causing reflection on his understanding of the problem

Ralph made several assumptions about this interviewee which he never externalized in a way that could be validated, challenged by the instructors when reviewing questions, or clarified by the interviewee. These included his identification of the former teacher in a user-centric role (as opposed to being a stakeholder that might have other valuable perspectives on user/student behaviors). He also assumed that the interviewee would understand analog and digital games as part of the same category of approaches within education—which can be seen as Ralph and the interviewee attempting to build shared meaning around the definition of games. When Ralph realized that the instructor's mother was not familiar with educational games, he reached out to bridge an identified gap (i.e., by offering up analog as well as digital game types), but only in support of the project direction and framing he had already assumed resonated with others. Rather than using the interview to expand his horizon and worldview regarding motivation and K-12 education, he instead *assumed* an overlap of worldviews—involving a variety of epistemological and ontological characteristics—on his own project terms (Figure 2). This approach assumed the presence of an intersubjective space between Ralph and the interviewee, even though this space did not appear to exist in the interview conversation.

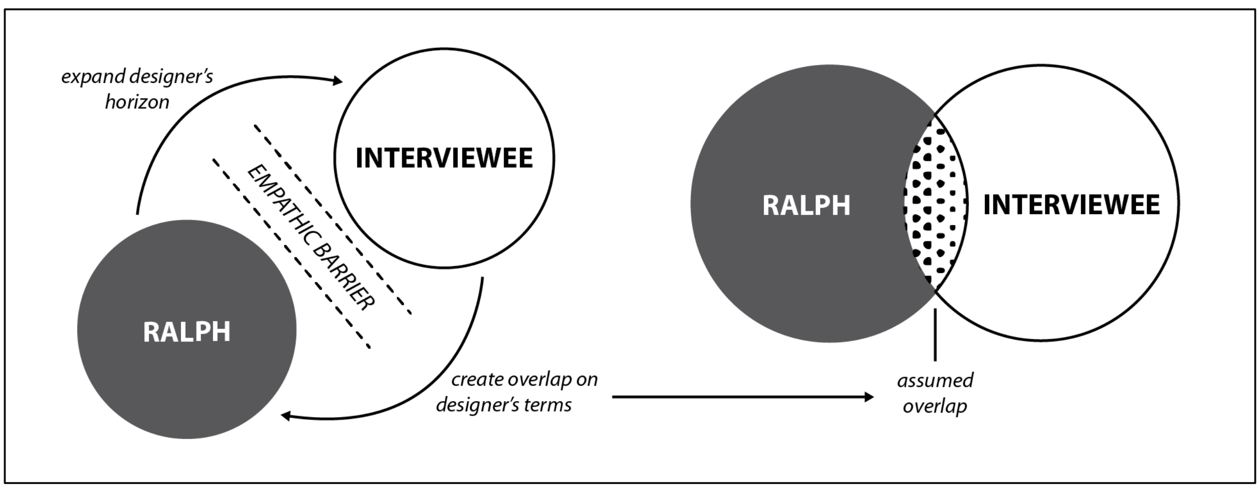


**Figure 2.** Ralph's empathic relationship to the interviewee (left), which assumed an overlap of subjective realities that did not exist.

Ralph's empathic horizon [36] was driven by his decision to pursue this project. Based on our knowledge of Ralph, he believed that only educational interventions that were intertwined with educational games had the potential to increase students' motivation. When confronted with an educator who did not share this perspective—primarily from an experiential point of view, but perhaps from a philosophical point of view as well—he was constrained by his treatment of his own subjective worldview as normative and even objective. This resulted in his construction of an assumed overlap of subjectivities between him and others. This relationship manifested as a malformed intersubjectivity, even though this intersubjective space had not yet formed. These intersubjective projections were complicated by Ralph's understanding of the interviewee's lived experience and the role of interviews in broadening a designer's understanding of the problem frame and solution space. Once it became clear that the interviewee did not have the knowledge of gaming necessary to inform his project, and perhaps may have even been dubious of gaming as an educational tool, Ralph took the opportunity to "educate" his interviewee on the purpose of educational or "serious" games, and their potential role in the classroom—abandoning the intended purpose of interviews in understanding stakeholder perspectives. In doing so, he unintentionally subverted the role of interviewing in a user-centered design approach, preventing the formation of an organic intersubjective space, furthering another's knowledge on his own terms rather than extending his own horizon of awareness on their terms.

### *5.3. Conflicting Worldviews Results in Paralysis*

The final vignette involves multiple students but focuses on Daniel and Mike. It occurred during the Spring 2016 semester during a focus group discussion about information literacy. Daniel has a disciplinary focus in electrical engineering technology and is an avid musician. Mike, has a disciplinary focus in mechanical engineering technology. He identifies as a "maker" whose career goal is starting his own business in digital manufacturing and prototyping. One of the instructors in the transdisciplinary learning environment was an engineering librarian who had particular interest in building students' information literacy skills, both generally and in the context of their project work. Past instructional efforts had included information retrieval techniques, use of scholarly databases, citation of materials, and how information can validate claims that arise in a design process. While students appeared to understand basic concepts of information literacy, their application of these concepts to projects was uneven. Few of the students appeared to enjoy the research component of their design projects.

In the second half of the fourth semester, students engaged in group projects where they set the topic and scope on their own, with instructor support. This setting required the students to identify areas of their interest and do research to identify what part of their interest might relate to a problem they could solve within the time constraints of the course. At the conclusion of the semester, the information literacy-focused faculty member led a focus group with the students to further understand students' information literacy development. The following conversation between two of the students reveals how these students conceptualized conflicting sources in ways that often caused project paralysis:

> **Daniel:** When I start finding [relevant resources] it could go very well, but as soon as I find that one source that is the contradiction to the entire thing that I'm writing about, or working on a project about… It doesn't matter when I find it. For our project if I had found something that said music people want to recycle or with this statement how [the likelihood of recycling is] 67% and not 30%.... you start getting this idea in your head that your project has no meaning anymore. There wasn't a problem in the first place.

That's why I was kind of laughing with [Ralph's] and my project, when we started finding information about privacy. Where people were already aware of the fact that was completely a contradiction to ours, and it complete[ly] demolished our project.

[…]

**Mike:** I think another thing that also, [is] not necessarily a specific article that confirms or denies, or something like that. When you get overwhelmed with varying or a wide variety of different reasons for something. And they all seem super credible […] you have all the information. You get too many varying perspectives on one thing. It makes you just not want to approach a problem at all sometimes.

When there's too much information, it's an overload of ideas about why things are working, you don't feel you can tackle them all, or approach any one of them confident that it's the best method. That also is a good method of shutting it down.

From this conversation, we constructed two parallel meaning fields (Table 4). The fields represent how these two students grappled with information in relation to their project work. They reveal different barriers to engaging with conflicting information, potentially reflecting different levels of coping with transdisciplinary patterns of thinking and acting.

*Table 4.* Parallel meaning fields of Daniel and Mike's utterances.

| Daniel | Mike |
|---|---|
| [possible psychological state: frustrated] | [possible psychological state: confused] |
| Quantitative information that conflicts with our framing of the problem is problematic.<br>**OR/AND** Quantitative information is easily compared.<br>**AND/OR** quantitative information that conflicts proves our project is worthless<br>**OR/AND** Conflicting information results in a stalemate and inhibits project work from proceeding.<br>**AND/OR** Information trumps ideas.<br>**OR/AND** Contradicting information has more weight than individual ideas.<br>**OR/AND** You cannot do anything if you have conflicting information.<br>**AND/OR** Information is true.<br>**OR/AND** Information can indicate the lack of a problem.<br>**AND/OR** Conflict about the form of a problem invalidates the underlying problem.<br>**OR/AND** Information can be compared with other information without any other considerations.<br>**AND/OR** Information shares the same underlying ontological and epistemological assumptions. | Multiple perspectives that conflict are problematic for the overall project.<br>**OR/AND** Perspectives are difficult to compare with each other.<br>**OR/AND** Too many perspectives result in designer paralysis.<br>**OR/AND** Too many varying perspectives result in a stalemate and inhibits project work from proceeding.<br>**AND/OR** Only a small number of perspectives can be taken into account.<br>**OR/AND** You cannot do anything if you have conflicting information.<br>**AND/OR** Conflicting perspectives represent different understandings of the same reality.<br>**AND/OR** Multiple perspectives can be credible and equally "true."<br>**OR/AND** One perspective must be selected as a "best method" or approach.<br>**AND/OR** Other perspectives are excluded when one perspective is selected. |

The two students struggled with different aspects of conflicting information, each with specific epistemological and ontological assumptions. We illustrate these assumptions, and their limitations, in Figure 3. Daniel posed a comparison of two objective-like pieces of information (67% v. 30% of users having an intent to recycle). He explained that the conflict between these numbers, devoid of context and treated as inmutably objective, would either result in the problem not existing (i.e., assuming only one of can be "true" and conflict makes both individually "untrue") or that the contradiction would negate or "demolish" the project scope/framing entirely. Mike expanded on Daniel's concerns and posed a different, non-binary, tension. To Mike, *too many* potential perspectives and data points could also result in indecision and inhibit action. In his case, information resulted not in a binary contradiction, which required abandoning the project, but rather an inescapable epistemic tension where ever-increasing complexity comes to control the project. These barriers also matched our observations of these students' working style, with Daniel preferring to think and contemplate, often at significant length, while Mike tended to speak and externalize as a means of thinking continuously adopting and abandoning different perspectives haphazardly—a technique he describes as searching for "the right one."

For both students, choices were always situated in non-overlapping ways. In Daniel's case, the non-overlapping data points were placed in forced opposition. Mike forced all solutions into an ongoing, yet discontinuous, cycle of adoption, dismissal, and replacement on the path towards an undefined "better" where each perspective was independent. In Daniel's project work this tension usually resulted in a convergent path towards a solution that matched the original problem, but which was continuously slowed by failed attempts to engage new perspectives. In Mike's project work, the discontinuous cycle resulted in the appearance of constant effort that resulted in solutions with a level of polish that seems mismatched to the level of effort that instructors observed.

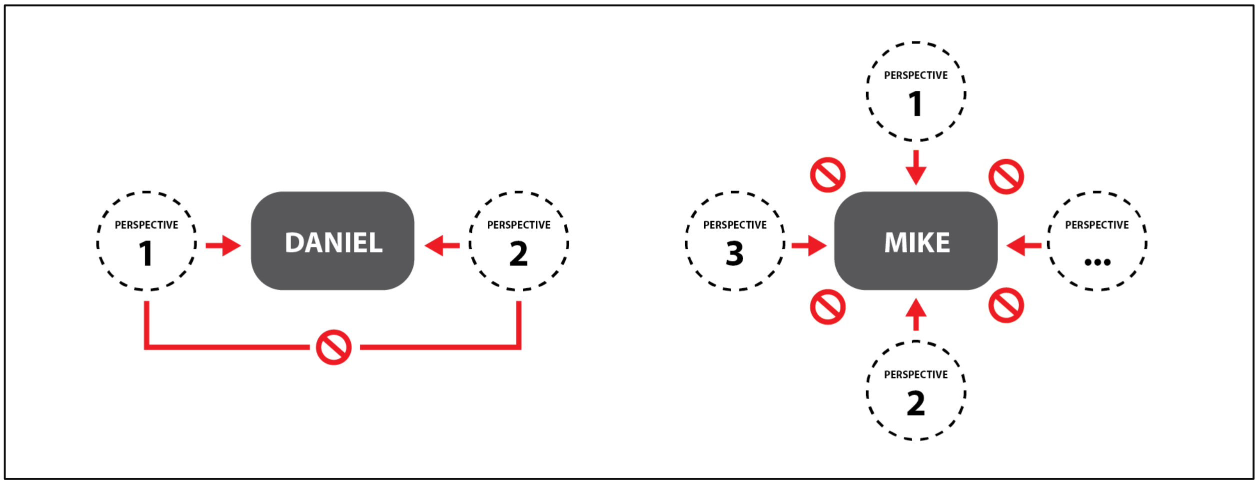


**Figure 3.** Mike and Daniel's approaches to conflicting information, both resulting in paralysis.

These two examples reveal the tensions students experience when attempting to reconcile or navigate multiple epistemological and ontological viewpoints. At the most basic level, binary conceptions create contradictions that can prevent the design process from proceeding for a student. However, even when students gain comfort with non-binary comparisons, there are still fundamental issues of *how* one productively engages with multiple conflicting perspectives at once.

This multiplicity of perspectives is critical to engaging in "wicked" problems that take into account sociotechnical complexity. Such problems require students to navigate a maze of contradictions. They require balancing inductive and deductive approaches to reasoning with generative, or abductive approaches that equally value problem framing and problem solving. What we observe in these students' behavior is that such contradictions are viewed not as recoverable snags but as terminal barriers to either new (Daniel) or existing (Mike) perspectives that they are seeking to implement.

## 6. Discussion

Through our analysis of these three vignettes and the embedded meaning reconstructions, we have identified that students were generally able to live and work comfortably within what they could frame as their *objective* world. However, the students' version of an objective world often assumed a fusion of their own subjective world and objective truth that raised cognitive dissonance when they attempted to be "transdisciplinary." The students had an internalized sense of objectivity, or at the very least the desire to work or appear to be "objective," from other course experiences. In short, students reasonably identified individual realities as subjective, and tried to construct meaning by integrating these subjectivities, but failed because their underlying objective view of the world made contradiction of the multiple subjective realities seem impossible.

Whether that yearning for objective understanding arises from engineering technology as a tacit disciplinary assumption, other coursework (e.g., K-12 experiences), or perhaps normative upbringing (e.g., race, class, gender, etc.) is unclear. Instructors in the transdisciplinary learning environment attempted to break down assumptions of complete objectivity and bridge from these perceived disciplinary epistemologies about knowledge and truth and ontologies in students' designerly identities into a more transdisciplinary approach. However, students were frequently and torn in observable, explicit ways between the epistemic assumptions of their disciplinary focus areas and the expectations of how a unity of multiple identities and epistemologies might be necessary in the transdisciplinary environment.

The students' assumed or attempted fusion of individual subjective realities with a monolithic objective reality is complicated. Our current assessment is that this fusion appears to be predicated upon students appreciating others' subjective realities as valid, real, and true, but such an appreciation must bend to accommodate their struggle or unwillingness to accept multiple realities as consistent with their core objective grounding. This attempt at fusing subjective and objective realities appeared to be driven by a desire for absolute truth, and a general discomfort with situations in which they needed to make meaning of others' subjective experiences or information in a broad sense. This behavior manifested in students' attempts to integrate multiple perspectives that they felt were in tension, including students' resistance to such apparent contradiction and the instructors' desire to understand the reasons behind those contradictions. The struggle with contradictions was particular salient as they seemed to, at times, not epistemically accept that true contradictions could exist within multiple subjective realities—resulting in an insurmountable mental barrier. These blocks between the interpretations of those experiences by others and themselves, and the inability to find a satisfactory integration, interrupt effective meaning making and limit development seen as critical to expert design behaviors in existing research [25].

Thus, students' experiences of engaging with problems containing multiple stakeholders, conflicting user views, or even information presented in varying contexts resulted in frustration and paralysis. This reveals a communicative barrier where students were unable to enter into a truly intersubjective space—where shared meaning is constructed and realized through interaction or reflection across subjective realities. This lack of intersubjective capacity was complicated by the formation of what we term a *fixed subjective* space, in which students were trapped by their own subjectively-anchored assumptions about the relationship between the objective and subjective worlds and the limitations of knowledge/validity claims in each world. This subjectivity is *fixed* in the sense that the students cannot escape their own subjectivity to appreciate and recognize the subjectivities of the "other" *on the other's terms*. Instead, the students' subjective notions of the world, conflated with a fixed objective reality, serve as an anchor for all interactions with other disciplines or stakeholders. In this fixed subjective space, students assumed the creation of an intersubjective space, but relied only upon an exclusively objective epistemology to make sense of it. This objectification of intersubjective space results in the misinterpretation of the subjective experiences of both themselves and others as both correct yet impossible. In addition, the objectification of the space often stripped any context, including alternate epistemological or ontological assumptions, from the data being sought or used. Because of this misalignment of expectations, students consciously engaged in user-centered design practices and attempted to engage with other disciplinary perspectives, but lacked the tacit knowledge, understanding, and sensemaking skills to appropriately bridge towards and integrate knowledge from each external source on its own terms.

One of the more profound barriers we uncovered in the meaning reconstruction process was the role of the learner in shaping their own subjective position in relation to other ontological and epistemological positions. In all three cases, the students anchored themselves to their own sense of the world, that we suggest likely arises from their lived experience prior to entering the program. When interacting with other objective or subjective realities, students either forced an overlap to exist on their own terms or repelled the conflicting reality. Ralph attempted to force an overlap between his own views on gaming and education and the former teacher he was interviewing. Instead of expanding his own horizon in order to understand and appreciate another's subjective reality, he instead used the interview as an opportunity to educate her on how education and gaming *should* overlap. In the examples of Paul, Daniel, and Mike, some form of conflicting reality presented itself—either as another disciplinary perspective or a combination of evidence within a disciplinary frame. In these examples, the student fought and actively repelled information that conflicted with or complicated their own, current view of the world. In the example of Paul, this repelling action minimized the value of transdisciplinary or disciplinary perspectives that were at odds with his disciplinary focus area. In the cases of Daniel and Mike, the repelling force prevented design action from moving forward constructively.

To fully engage with the goals of the Engineer of 2020 [4], we propose that attention to core issues that relate to tacit knowledge—through students' sensemaking, construction of knowledge, and application of that knowledge to specific design situations—should represent a substantial and sustained focus on the part of engineering educators. While there has clearly been positive movement as evidenced by the adoption and integration of designerly methods and approaches, such as user research and engagement in the social world of potential stakeholders, in this paper we have found that this immersion in designerly behaviors is not sufficient to shift the epistemological and ontological stances of engineering students. Rather, we posit that shifting these structures of individual meaning making requires additional individual attention to students' meaning making practices, and the ways in which these practices are informed and sustained through students' identity commitments in the subjective and normative formal worlds.

## 7. Future Work and Conclusion

In this paper, we have explored how a lack of intersubjective ability on the part of students hampered their ability to truly engage with an integrated, transdisciplinary design ontology. This developmental challenge was brought to light within the context of projects designed to encourage the development of a socially-aware engineering identity, but also appear consistent with barriers to the development of design ability noted by other scholars [e.g., 1,6,10,22]. While these previous approaches have engaged with observable behaviors and mindsets that relate to taking on and performing in relation to a design ontology, it has been rare for scholarship to engage with the objective and subjective barriers on an ontological and epistemological level. The vignettes we have presented demonstrate that the performance of user-centered or human-centered activities (e.g., interviews, considering alternate disciplinary perspectives on human behavior) does not automatically shift a student's underlying ontological position. Instead, these observable behaviors may mask students' ability to mentally account for the presence of multiple subjective realities if these contradictions are not directly confronted, and may inhibit students from developing a fully functional socially-aware engineering identity. In sum, we see that for these students, the learning or practice of designerly behaviors is not inherently formative [37] of a designerly identity. This notion is supported by other scholars, who have highlighted the role of instructors in shaping appropriate epistemological and ontological structure *in relation to* domain knowledge [38,39]. In particular, we wish to note the importance of instructors first being willing to embrace the interpretive and social implications of engineering in their classrooms; without this initial attention to and shift away from dominantly positivist epistemologies, no movement can expect to be attained towards the social and situated dimensions of engineering activity by engineering students, regardless the learning activities or methods employed.

While this study does indicate the need for further reflection on how engineering educators may encourage students to shift their ontological perspective, there are also notable limitations to our method and sample. The students enrolled in this experimental transdisciplinary program were attracted to the promise of hands-on learning, and were simultaneously enrolled as degree-seeking students in other departments during their first two years of the program. This tension of academic commitments and personal educational preferences may have contributed to the unique behaviors and barriers we observed. Additionally, the critically-informed meaning reconstruction method we have used relies upon researcher interpretations of student behaviors. While we have included multiple researcher perspectives, all from researchers who have extensive experience in talking with and observing these students, it is impossible to account fully for shifts in students' thinking over time, or instances where students' external behavior is inconsistent with their internal beliefs.

We conclude with implications for encouraging socially-aware identity formation in engineering education. Our findings indicate multiple potential areas for future research, which if taken up, may facilitate a greater understanding of barriers that educators must help students confront and overcome. First, articulation of students' tacit beliefs and knowledge structures in relation to taking on an engineering identity is critical to "language" and externalize the disciplinary assumptions that may be hostile or inconsistent with a socially-aware, pluralistic approach to complexity in engineering practice. Additional research on how students engage with sociotechnical complexity, including comparing evidence from multiple disciplinary perspectives and epistemologies, is needed to reveal characteristic barriers to student development, and methods to externalize felt contradictions. Second, additional means of externalizing students' cognitive routines, without looking to known designerly behaviors, may also prove to be valuable in confronting barriers in knowledge transfer among disciplines or between the designer and users/stakeholders. Established instructional techniques from the design pedagogy literature such as guided reflection and critique may bring about greater awareness towards and transformation of intersubjective ability, encouraging students to regularly confront external perspectives on their design activity and articulate rationale for their decisions.

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