# Developing a Socially-Aware Engineering Identity Through Transdisciplinary Learning

**COLIN M. GRAY* & TODD M. FERNANDEZ**
PURDUE UNIVERSITY

*Corresponding Author: Colin M. Gray, Purdue University; Email: gray42@purdue.edu

**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. In this paper, we describe how students in a transdisciplinary undergraduate program struggle to engage with ontological and epistemological perspectives that draw on that 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 these students to reveal characteristic barriers in engaging with other subjectivities, and related epistemological and ontological claims implicit in these subjectivities. 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]. Such challenges 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 sensemaking 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" (i.e., 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]), grounded in more inclusive, empathetic, and nuanced ways of engaging in the sensemaking process. These literacies must prepare students to deeply understand users' needs, articulate sociotechnical and cultural boundaries [8], and 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]). These literacies are not just a means of externalizing the results of engineering activity, but also serve as a crucial tool for engaging in the process of engineering design and citizenry by connecting their own identity with the work they are doing and those who their work is for. 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' internalized identity 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 views on reality that undergird students' operationalization of human-centered design skill. 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 an engineering design identity that relies 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.

## 2. Purpose

Our purpose is to understand the epistemological bases and ontological viewpoints which ground students' construction of meaning and the flexibility of students' conscious engagement with these epistemologies and ontologies. We explore these ideas in the context of students' design activity amidst their acquisition of disciplinary knowledge and engagement with user-centered design methods. This exploration occurs longitudinally as students learn to act in designerly ways in a transdisciplinary classroom. We target students' epistemologies and ontologies to explore how they conceptualize and internalize stakeholder roles, disciplinary knowledge, and the role of users in their 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.

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, and have meaning because of the intersubjective space that forms among multiple human actors. 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. With one definition of design being the attuning of oneself to making intentional change in the world [15], a brief background of research on the formation of students' designerly identities is useful.

Work on designerly identities in the literature includes discussions of what designerly identities look like in professionals and how those identities develop in students. This work includes 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 the progression of logic described by Dorst [25] in relation to expert design identities is based on strong indications of a progression from objective to subjective to intersubjective ways of viewing the world, the actual discussion of epistemological bases is largely 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. Different epistemologies of knowledge are implicit in the two examples above which look at how students develop designerly identities. However, 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 missing. 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 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 draws 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 study we employ a dialogical meaning construction approach to explore the epistemological and ontological assumptions that ground students' design activity. The meaning reconstruction approach we employ is based in 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. This critical theoretical perspective has informed our research approach throughout the data collection and analysis of student behaviors in a new transdisciplinary major. The research effort comprises a multi-year ethnography consisting of 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 including our theoretical perspective, the programmatic context in which the study is situated as well as how we collected data in it, the students included in the results section, our positionality as researchers in this context, and our analytic method.

### *4.1. Theoretical perspective*

In this paper we adopt a critical theoretical perspective, focusing on how students build identities as designers and transdisciplinary thinkers, and how this identity construction takes place in relation to our 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 allows access into 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 several important ways. First, while criticality has been most commonly deployed in engineering education research to look at issues of equity, justice, diversity, and inclusion, 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 typical notions of students moving from objective, to subjective, to intersubjective ways of seeing reality. Finally, the complexity and intertwined nature of speech acts of students with the surrounding institutional context, their development as a learner, and their own lived experiences informs our deconstruction of meaning. While scholars in engineering education might refer to this deconstruction as post-structuralist [32], we undertake the process through a critical-structuralist orientation.

### *4.2. Data and context*

Data for this paper draws on a larger research engagement focused on 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. To crystallize the transdisciplinary nature of the program for the students, 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 program, students take courses from the transdisciplinary program, the College of Technology, and across the larger university. Within the transdisciplinary program, students enroll in a course or courses every semester that account for 8 contact hours (4 credit hours) taught using a set of overlapping studio and seminar pedagogical approaches. These courses typically focuses on broad problems that model the social turn in engineering design and hint at 'wicked' problems. Typically, students work on both individual and team design 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 designed to both introduce new learning opportunities as well as create a space for students to engage in synthesis of their other coursework.

The data collection process within the program has been intentionally layered to collect multiple streams and multiple perspectives of data representing the experience shared by educators and students. Broad data collection and educational research and assessment has been a core focus of the program since development began, and has occurred throughout the length of the program. 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.

Our focus for this paper is on students' classroom activity during the fourth and fifth semesters, where students worked on a combination of individual and team design projects designed to elicit and activate 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 had to design and build 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 and three instructors designed and facilitated the fifth semester course (with one overlapping instructor from the previous semester). These included one instructor 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 fourth semester instructor), and one with a background in engineering and librarianship. 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.

### *4.3. Participants*

While the number of students in the program has varied from semester to semester, the students used as examples in this paper have been enrolled for the past three years. During the most recent 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. 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.

### *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 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 method by which emergent hypotheses are used to identify potential research paths and is then combined with further data collection and fieldwork to lead to the selection of appropriate analytical techniques [34]. This approach allowed us to identify emergent themes 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 reflexivity and allow for multiple perspectives on the data—important elements of rigor in the qualitative research tradition.

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 not to discover a true or accurate meaning or sets of meaning, but rather 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."

### *4.5. Author positionality*

This section addresses positionality in two ways for each of the authors. Because the authors have been intimately involved with the development and execution of the program, we believe a clear statement of our positionality and relationship to the program is important. The first part of the positionality is a discussion of our roles within the transdisciplinary program, while the second part relates to the researchers' professional background and research focus.

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. He co-taught the studio experience in the Spring 2016 semester, and has co-led the research and evaluation team over the past two years. Prior to becoming involved with the transdisciplinary program he completed his 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 consultant. His research focuses on entrepreneurial cognition and measurement of complex cognition. Specifically, he focuses on characterizations and comparisons of expert and novice behavior as seen critical assessment of epistemologies of educational measurement and assumptions in assessment validation techniques. He also studies inter-relationships between design and entrepreneurship as they apply to pedagogies that encourage sensemaking and development of student identities.

## 5. Three Vignettes

Based on our long-term engagement in the transdisciplinary educational context, we used strip analysis to identify potential barriers to students' development of intersubjective ability. These potential hypotheses were expanded and articulated through explicit interview and focus group questions, and were also at the center of a set of designed course experiences that were intended to build empathic ability and awareness of multiple subjectivities.

We present three vignettes from this long-term engagement to allow analysis on an individual case level, using a reporting approach inspired by the critical incident technique [35] to portray the complex relationships among the students, instructors, and multi-semester learning experiences. Each vignette includes the perspective and speech act(s) or observations of one or more specific students, which are then methodically expanded using a meaning reconstruction approach [17,19] to allow access to the meaning-making strategies employed by the students and the epistemological and ontological assumptions that undergird these strategies. 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 occurred involved Paul. Paul is a high performing student with a disciplinary focus in mechanical engineering technology. Although he spent several formative years in a developing nation, he attended a local religious high school. His primary professional interests are in helping underprivileged groups using his degree. While the critical event occurred during Fall semester of 2016, the triangulation and observations cross multiple semesters. 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 required and monitored by a mentor and academic advisor, and were well known to the teaching faculty. The projects students completed in the design studio portion of the transdisciplinary learning environment necessitated students to use these outside perspectives without prescribing *how* they should or could be used.

During the Spring 2016 semester, Paul worked with other students on an open-ended project; his team selected water recovery on a remote Pacific island as their problem and context, and 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 framework of resources (e.g., prototyping materials, conceptual advice) to encourage rapid prototyping across increasing levels of fidelity to identify and mitigate construction barriers, allowing students to take ownership of any disciplinary knowledge or just-in-time learning that may be 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 levels of engineering complexity, including the lifespan of the plastic sheeting identified, the pathways intended for water runoff, means of water collection and storage, and planning for typhoons or other storms that may disturb the still. 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 knowledge contextualizes a specific speech act the following semester in commentary 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.

[possible psychological state: frustration]

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 TST 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.

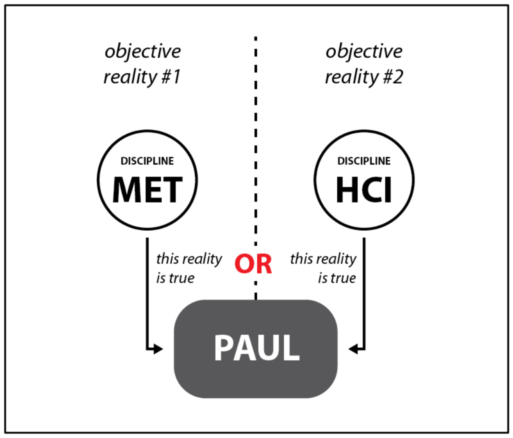


**Figure 1.** Paul's tension between two competing "objective" realities: that of his instructor (HCI) and that of his disciplinary focus (MET).

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 comes came about during the Fall 2016 semester, involving 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 engage in multiple interviews with individuals from student identified user or stakeholder groups as part of the research component of a two-semester individual project.

Ralph was interested in game design and education, and had identified "serious games" as a potential project focus and chose as his project the design of a math-focused game for use in k-6 classrooms. Even though user/stakeholder interviews were required, he had substantial discomfort about completing these interviews, and stalled for multiple weeks to avoid or put off the assignment, as had been typical for him and other students in previous semesters. He was willing to interview or test with his peers in the course, but did not appear to acknowledge the drawbacks of using college students as stand-ins for users of the target age group. After the mid-point of the semester, one of the course instructors informed Ralph that her mother—a former elementary school teacher—would be attending the for a day of class 1-2 weeks later. The instructor offered her mother as a potential interviewee and provided contact information and other guidance. Ralph agreed in advance to conduct the interview on a specific class day, and prepared a specific set of questions for the interview, which he reviewed 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 were present for almost 90 minutes of a 110 minute class period. With 20 minutes left, one instructor strongly suggested that Ralph begin the interview, and he complied. The observation notes from a researcher that was present in the classroom 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.]

This conversation and the acts which preceded it were used to construct a meaning field that demonstrates the range of possible meanings that could be ascribed to Ralph 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.

| |
|---|
| [possible psychological state: avoidant, nervous] |
| 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) and solution space (e.g., games as a motivational learning tool), which from observation were heavily interlaced with his personal K-12 experiences. He also made several assumptions about this interviewee which he never externalized in a way that could be validated or challenged by the instructors. These included the identification of the former teacher as a potential user (as opposed to being a stakeholder that might have other valuable perspectives on user/student behaviors) and the assumption that the interviewee would understand analog and digital games as part of the same category of approaches within education. 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.

While subtle in the example above, in which communication with a stakeholder is normatively treated with deference, the manifestation of the assumed overlap was apparent throughout his project. In communication about Ralph's project, most experiences were framed with positivist language (e.g., "education is") rather than more language that is indicative of a more subjective epistemology (e.g., "my experience in education is"). This normative-objective fusion manifested further when Ralph worked with instructors to find scholarly research that he felt he needed to *support* rather than *inform* the project decisions he was making. Based on further notes, project artifacts, and instructor interviews, we found those pieces of information failed to exist, Ralph struggled greatly because he felt his beliefs (i.e., his reality) was being undermined.

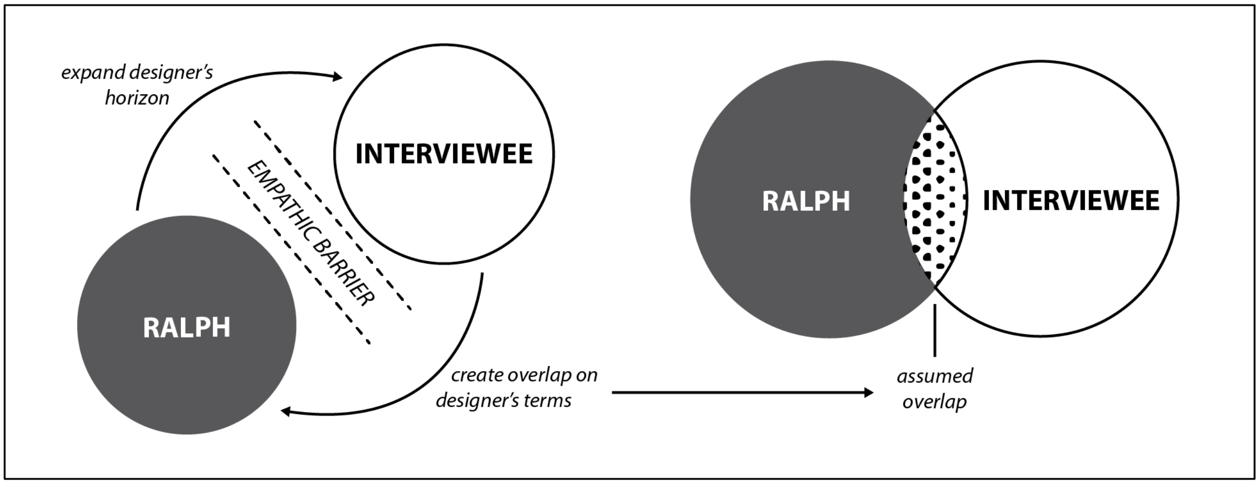


**Figure 2.** Ralph's empathic relationship to the interviewee (left), which assumed an overlap of subjective realities that did not exist.

Ralph's empathic horizon [36] was limited such that he could only identify educational interventions that bring about motivation as being intertwined with gaming. When he was 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 own worldview and this related horizon, resulting in his construction of an assumed overlap of subjectivities. This relationship asserted intersubjectivity, even though this intersubjective space had not yet had a chance to form. 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 switched "modes" and took the opportunity to "educate" his interviewee on the purpose of educational or "serious" games, and their potential role in the classroom. In doing so, he unintentionally subverted the role of interviewing in a user-centered design approach, preventing the formation of an organic intersubjective space as well as furthering another's knowledge on his own terms rather than extending his own horizon of awareness.

### *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 with the students on information literacy. While multiple students were present for this vignette, we highlight two students. Daniel has a disciplinary focus in electrical engineering technology and is an avid musician. The second student, Mike, has a disciplinary focus in mechanical engineering technology. He identifies as a "maker" and wants to start and own 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 the way that information can be used to validate claims that arise in a design process. While students appeared to understand basic concepts of information literacy, their application of these concepts in their project work was uneven, and few students appeared to enjoy the research component of their design projects.

In the second half of the Spring 2016 semester, students engaged in group projects where they set the topic and scope on their own, with instructor support. This setting and scoping 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 this semester, a faculty member whose research interests include information literacy, especially in design, led a focus group with the students to further understand students' perspectives on and understandings of their information literacy development. The following conversation between two of the students, reproduced below, reveals how these students conceptualized conflicting sources in different ways, often causing paralysis of action:

**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.

These speech acts were used to construct two parallel meaning fields (Table 4), representing how these two students grappled with information in relation to their project work. These meaning fields 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. |

Each student was struggling with a different aspect of conflicting information, each with underlying epistemological and ontological assumptions and limitations illustrated 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 data points, devoid of context, would either result in the problem not existing (i.e., assuming only one of those data points can be "true" and conflict makes both individually "untrue") or that the contradiction would negate or "demolish" the project scope/framing entirely. Mike posed a different non-binary tension while expanding on Daniel's concerns, revealing that *too many* potential perspectives and data points could also result in indecision and inhibit action. In this latter case, information resulted not in a binary contradiction, which required abandoning the project, but rather an inescapable epistemic tension relating to a confluence of complexity that 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 while he tried and abandoned different perspectives haphazardly, a technique he describes as searching for "the right one." For both, 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 at the end of projects with a level of polish that seems mismatched to the level of effort that instructors observed.

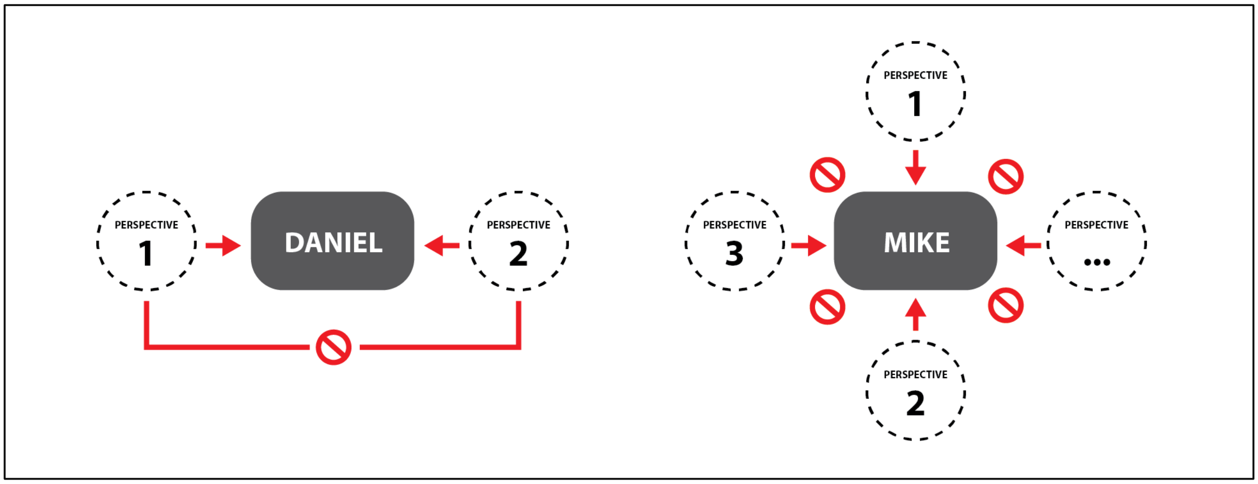


**Figure 3.** Mike and Daniel's approaches to conflicting information, both resulting in paralysis.

These examples reveal the tensions students experience when attempting to reconcile or navigate multiple epistemological and ontological viewpoints. At the most basic level, binary contradictions may shut the design process down for a student, but even once awareness of complexity beyond binary, quantitative comparisons is realized, 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, yet require students to navigate a maze of contradictions, balancing typical inductive and deductive approaches to reasoning with generative, or *abductive* approaches that value novelty over satisficing. What we observe in these students' behavior is that such contradictions are viewed not as recoverable errors but as a terminal barrier to either the new (Daniel) or existing (Mike) perspective 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 often torn 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.

## 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.

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.

## 8. Acknowledgements

We would like to express our sincere thanks to the researchers engaged in this multi-year effort, including Iryna Ashby, Terri Krause, and Denise Wilder. Their efforts in producing a rich observation and interview record, in addition to their peer debriefing of these vignettes, is greatly appreciated. In addition, we greatly value the peer debriefing and editing efforts of Marisa Exter.

## 9. References

1. H. Rittel and M. Webber, Planning problems are wicked problems, in N. Cross (Ed.), *Developments in design methodology,* John Wiley & Sons, Chichester, 1984, pp. 135-144.
2. S. Sheppard, K. Macatangay, and A. Colby, *Educating engineers: Designing for the future of the field.* Jossey-Bass, San Francisco, CA, 2009.
3. R. S. Adams, S. R. Daly, L. M. Mann, and G. Dall'Alba, Being a professional: Three lenses into design thinking, acting, and being, *Design Studies*, **32**(6), 2011, pp. 588-607.
4. U S. National Academy of Engineering *The engineer of 2020: visions of engineering in the new century*, National Academies Press, Washington, DC, 2004.
5. NAE Grand Challenges for Engineering, *National Academy of Engineering*, http://www.engineeringchallenges.org, Accessed January 14, 2017.
6. C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, Engineering design thinking, teaching, and learning, *Journal of Engineering Education,* **94**(1), 2005, pp. 103-120.
7. C. Cazden, B. Cope, N. Fairclough, J. Gee, M. Kalantzis., G. Kress, . . . M. Nakata, A pedagogy of multiliteracies: Designing social futures, *Harvard Educational Review,* **66**(1), 1996, pp. 60-92.
8. E. Crewe, The Silent traditions of Developing Cooks, in R. D. Grillo & R. L. Stirrat (Eds.), *Discoveries of Development,* 1997. doi:10.1163/_q3_SIM_00374
9. R. C. Campbell, Caring in engineering: How can engineering students learn to care? In J. Lucena (Ed.), *Engineering education for social justice: Critical explorations and opportunities*, Springer, Dordrecht, NL, 2013, pp. 111-131. doi:10.1007/978-94-007-6350-0_6
10. C. B. Zoltowski, W. C. Oakes, and M. E. Cardella, Students' ways of experiencing human-centered design, *Journal of Engineering Education*, **101**(1), 2012, pp. 28–59.
11. K. Dunsmore, J. Turns, and J. M. Yellin, Looking toward the real world: Student conceptions of engineering, *Journal of Engineering Education*, **100**(2), 2011, pp. 329–348. doi:10.1002/j.2168-9830.2011.tb00016.x
12. M. Hynes and J. Swenson, The Humanistic Side of Engineering: Considering Social Science and Humanities Dimensions of Engineering in Education and Research, *Journal of Pre-College Engineering Education Research,* **3**(2), 2013, pp. 31-42.
13. S. Allie, M. N. Armien, N. Burgoyne, J. M. Case, B. I. Collier-Reed, T. S. Craig, . . . N. Wolmarans, Learning as acquiring a discursive identity through participation in a community: Improving student learning in engineering education, *European Journal of Engineering Education,* **34**(4), 2009, pp. 359–367. doi:10.1080/0304379090298945
14. G. L. Downey, and J. C. Lucena, Knowledge and professional identity in engineering: code-switching and the metrics of progress, *History and Technology,* **20**(4), 2004, pp. 393–420. doi:10.1080/0734151042000304358
15. H. G. Nelson and E. Stolterman, *The design way: Intentional change in an unpredictable world,* 2nd ed., MIT Press, Cambridge, MA, 2012.
16. M. Crotty, M. *The foundations of social research: Meaning and perspective in the research process*, Sage Publications Ltd, Thousand Oaks, CA, 1998.
17. P. F. Carspecken, *Critical ethnography in educational research: A theoretical and practical guide*. Routledge, New York, NY, 1996.
18. R. Zhang, and P. Carspecken, Content inference fields in intersubjective space: Transpersonal position, illocution, and logic in the analysis of human interactions, in B.

Dennis, L. Carspecken, and P. F. Carspecken (Eds.), *Qualitative research: A reader in philosophy, core concepts, and practice,* Peter Lang Publishing, New York, NY, 2013, pp. 201-242.

19. C. M. Gray, A. L. Toombs, and C. McKay, Meaning Reconstruction as an Approach to Analyze Critical Dimensions of HCI Research, in *CHI EA '16: CHI'16 Extended Abstracts on Human Factors in Computing Systems,* ACM Press, New York, NY, 2016, pp. 328-340. doi:10.1145/2851581.2892571
20. J. Habermas, Individuation through socialization: On George Herbert Mead's theory of subjectivity, in *Postmetaphysical thinking: Philosophical essays*, MIT Press, Cambridge, MA, 1992, pp. 149-204.
21. N. Cross, *Designerly ways of knowing,* Birkhäuser, Basel, Switzerland, 2007.
22. D. P. Crismond and R. S. Adams, The informed design teaching and learning matrix, *Journal of Engineering Education,* **101**(4), 2012, pp. 738-797.
23. B. Lawson and K. Dorst, *Design expertise*, Architectural Press, Oxford, UK, 2009.
24. S. R. Daly, R. S. Adams, and A. M. Bodner, What does it mean to design? A qualitative investigation of design professionals' experiences, *Journal of Engineering Education,* **101**, 2012, pp. 187–219.
25. K. Dorst, The core of "design thinking" and its application, *Design Studies*, **32**(6), 2011, pp. 521–532.
26. T. Hamilton, *Understanding the Black College Student Experience: The Relationships Between Racial Identity , Social Support , General Campus , Academic , and Racial Climate , and GPA*, unpublished doctoral dissertation, Seton Hall University, South Orange, NJ, 2009.
27. J. L. Huff, *Psychological journeys of engineering identity from school to the workplace: How students become engineers among other forms of self*, unpublished doctoral dissertation Purdue University, West Lafayette, IN, 2014.
28. A. Godwin, G. Potvin, Z. Hazari, and R. Lock, Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice, *Journal of Engineering Education*, **105**(2), 2014, pp. 312-340.
29. D. M. Hatmaker, Engineering identity: Gender and professional identity negotiation among women engineers, *Gender, Work & Organization*, **20**(4), 2013, pp. 382-396.
30. A. D. de Figueiredo, Toward an Epistemology of Engineering, in D. Goldberg and N. McCarthy (Eds.), *Workshop on Philosophy & Engineering* (WPE 2008), Royal Engineering Academy, London, UK, 2008, pp. 94-95.
31. K. Beddoes, and M. Borrego, Feminist theory in three engineering education journals: 1995–2008, *Journal of Engineering Education*, **100**(2), 2011, pp. 281–303. doi:10.1002/j.2168-9830.2011.tb00014.x
32. M. Koro-ljungberg, and E. P. Douglas, State of qualitative research in engineering education : Meta-analysis of JEE articles, 2005-2006, *Journal of Engineering Education*, **97**(2), 2008, pp. 163–175.
33. J. Evans, *What is transdisciplinarity?*, 2014, Retrieved from https://polytechnic.purdue.edu/blog/what-transdisciplinarity
34. M. Agar, *Speaking of ethnography,* Sage Publications, Beverly Hills, CA, 1986.
35. J. C. Flanagan, The critical incident technique, *Psychological Bulletin*, **51**(4), 1954, pp. 327-358.
36. D. McDonagh-Philp, and H. G. Denton, User-centred design and the focus group:

Developing the student designer's empathic horizons, in R. Kimbrell (Ed.) *Design and technology International Millennium Conference*, The D&T Association, Wellesbourne, UK, 2000, pp. 111-116.
37. J. R. Edwards, & R. P. Bagozzi (2000). On the nature and direction of relationships between constructs and measures. *Psychological Methods*, *5*(2), 155–174. https://doi.org/10.1037/1082-989X.5.2.155

**COLIN M. GRAY** is an Assistant Professor at Purdue University in the Department of Computer Graphics Technology and a Fellow in the Educational Research and Development Incubator. He holds a PhD in Instructional Systems Technology from Indiana University Bloomington, a MEd in Educational Technology from University of South Carolina, and a MA in Graphic Design from Savannah College of Art & Design. His research focuses on the role of student experience in informing a critical design pedagogy, and the ways in which the pedagogy and underlying studio environment inform the development of design thinking, particularly in relation to critique and professional identity formation. His work crosses multiple disciplines, including engineering education, instructional design and technology, design theory and education, and human-computer interaction.

**TODD M. FERNANDEZ** is a PhD candidate at Purdue University in the School of Engineering Education. He holds Masters and Bachelors degrees in mechanical engineering from the Rochester Institute of Technology. His research focuses students' development of entrepreneurial cognition. He focuses on this work using critical theory, design theory, instrument development to research epistemological beliefs of researchers, students, and faculty related to entrepreneurship and innovation. In parallel, he works on using entrepreneurial and institutional change concepts to study and advocate for change in engineering education.