Facilitating Problem Framing in Project-Based Learning

Vanessa Svihla
University of New Mexico, vsvihla@unm.edu

Richard Reeve
Queen's University, reever@queensu.ca

Recommended Citation

THE INTERDISCIPLINARY JOURNAL OF PROBLEM-BASED LEARNING

Facilitating Problem Framing in Project-Based Learning

Vanessa Svihla (University of New Mexico) and Richard Reeve (Queen's University)

Abstract

While problem solving is a relatively well understood process, problem framing is less well understood, particularly with regard to supporting students to learn as they frame problems. Project-based learning classrooms are an ideal setting to investigate how teachers facilitate this process. Using participant observation, this study investigated how teachers supported students in taking ownership over the framing of problems in a charter school that serves students who have been underserved by traditional schooling. Data include audio/video records, field notes, interviews, and student work from a nine-week project. Interaction analysis was used to examine ownership and learning over time. Analysis suggests that providing a relevant yet revisable design problem, giving instruction about design process as iterative, and problematizing a model of design process supported students in taking ownership over the framing of the problem; students were motivated to pose questions and gathered information purposefully, thereby learning in the process.

Keywords: project-based learning, designing, problem framing

Introduction

This study is not about solving specific problems. In fact, we don't report on problem–solving outcomes. Rather, the key concern here is on the tremendous utility that ongoing problem framing holds for learning—provided students have genuine ownership over the ill-structured problems on which they are working. We present a case to show how teachers launched a project focused on designing temporary shelters for homeless clients; the teachers envisioned that each group would produce a specific design for a specific client. However, the teachers also wanted the students to frame the problem and shifted the locus of control to the students, who reframed the problem from one of charity to one about social justice: in effect, they sought to solve the larger and more general problem of homelessness and not just the problem of specific local homelessness.

In school settings, the problems that students typically are confronted with are well-structured (Jonassen, 2000), with the focus being on finding the correct solution using the canonical solution pathway. However, in these well-framed and well-structured problems, the process by which the problem develops is seldom within the control of the students (Scardamalia, 2002). Recent changes to curricular standards in the United States call upon teachers to engage their students in less well-structured, more generative problem solving (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), but this has proven to be challenging for teachers (Dole, Bloom, & Kowalske, 2016) and students alike. Thus, even when students are presented with authentic dilemmas that require decisions about possible solutions, there are few cases in which students actually get to take the necessary time to frame the problem they are solving.

This can even be a tension in project-based learning (PBL) classrooms, where students are sometimes given the semblance of control but only over a limited part of the task. For instance, they may be permitted to make decisions about the format (poster, pamphlet, or presentation) of a final product but not about the scope of content, much less the nature of the problem to which they are committing their attention. Although the driving question ought to present "real-world problems that students find meaningful, thereby motivating them to take ownership of the questions and to thoughtfully

pursue answers to them" (Marx, Blumenfeld, Krajcik, & Soloway, 1997, p. 345), in practice even PBL can be highly constrained in terms of the leeway students are given to determine the problem they are to work on. This can render potentially rich, ill-structured problems into well-structured problems. While a great deal is known about how students learn as they solve well-structured problems (Mergendoller, Maxwell, & Bellisimo, 2006; Savery, 2006; Strobel & Van Barneveld, 2009; Walker & Leary, 2009), relatively little is known about how students learn as they themselves frame ill-structured problems. The purpose of this study is to investigate how teachers might support students in framing ill-structured problems within PBL settings and the resulting engagement by students.

Problem framing has been considered one of the most important components of problem solving, at least in terms of professional designers producing a high-quality solution (Basadur, Graen, & Green, 1982). In professional design settings, problem framing is where much of the learning occurs, as the designer must learn about the problem; problem framing prompts purposeful gathering of information and sets up the need for critical reflection. We see problem framing as therefore holding great potential for learning even outside of professional design settings, particularly when students have ownership over ill-structured problems on which they are to work.

Literature Review

Problem framing is present and valued in a range of fields, from art to business to engineering design and science (Runco & Chand, 1994). As a result, it has numerous aliases: problem posing, problem representation, problem defining, problem finding, and problem construction. Regardless of how it is labeled, the most promising place to look for learning through problem framing is in the context of ill-structured problems. Such problems are typically design problems, even when they are not named design problems by a given field. For instance, scientists don't often reference themselves as designers, yet they *design* investigations, procedures, and data representations. Further, the problems faced by society are increasingly complex, ill-structured problems, and people are turning to design as a way to solving them (Dorst, 2015; Homer-Dixon, 2000). Henceforth, we refer to the solvers of ill-structured problems, regardless of discipline, as designers rather than as problem solvers.

We review literature to build an operational definition of problem framing that includes its characteristics and activities. We consider ways that these activities enter or align with typical instruction in school settings. We then consider the barriers that might prevent problem framing from occurring in the classroom and how teachers might mitigate these barriers.

Framing Ill-Structured Problems

There is variability in how much and what activities a designer undertakes to frame a problem (Cross, 2001; Restrepo & Christiaans, 2003). This has made operationalizing problem framing difficult. Most descriptions of problem framing activities include information gathering, ideation, and evaluation of ideas generated.

More experienced designers gather more information for understanding the problem (Bursic & Atman, 1997), using various means to do so. For instance, designers might assess customer needs, investigate and analyze design requirements and constraints, research previous solutions, and identify resources (Dominick, 2001). Designers gather information to clarify aspects of the problem, eliminate untenable tentative solutions, explore possible ideas, and address a lack of knowledge (Tracy, 2005). In doing so, they focus on existing and alternative solutions (Morozov, Kilgore, & Atman, 2007) and consider a broad problem space (Atman et al., 2008). A key insight is that when designers gather information, they continue to learn about the problem. Even relatively inexperienced designers learn a considerable amount of disciplinary content as they are engaged in framing problems (Svihla, 2009).

To make progress in framing a problem, designers generate tentative conjectures about possible solutions. There are many approaches taken to generating such ideas (Dadich, 2014; Dorta, Perez, & Lesage, 2008; Neeley, Lim, Zhu, & Yang, 2013; Verhaegen, Peeters, Vandevenne, Dewulf, & Duflou, 2011). Commonly, problem framing also involves evaluating the ideas generated (Basadur et al., 1982) and considering ideas in light of costs and benefits to arrive at priorities (Morozov et al., 2007).

However, models of problem solving and designing often include problem framing (or a similar construct) as a separate step from information gathering, ideation, and evaluation (Jonassen, 1997; Wynn & Clarkson, 2005). Therefore, detailing the specific activities that support problem framing does not adequately detail problem framing. We argue that in order for activities such as information gathering, ideation, and evaluation to constitute problem framing, the designer must take ownership of the problem. Not doing so renders these activities inert. We therefore next consider why agency and ownership matter in problem framing and what *agentive* problem framing entails.

Agency and Ownership in Problem Framing

In professional settings, designers have ownership of problems; they choose which aspects of the problem space to attend to as they bound it (Schön, 1983). They make decisions about how to proceed. They decide "what to do (and when) on the basis of a personally perceived and constructed

design task, which includes the design problem, the design situation and the resources (time) available, as well as the designer's own design goals" (Dorst & Cross, 2001, p. 432). Thus, problem framing carries with it a sense of agency (Hanauer, Frederick, Fotinakes, & Strobel, 2012).

When designers gather information, they do so purposefully, driven by "the need to structure the design problem" (Restrepo & Christiaans, 2003, p. 11). This gets at the essence of why problem framing is necessary in dealing with design problems. Design problems do not arrive as tidy, rational, deterministic problems, the way many problems that students solve in schools do. Even when issued as a design brief—a description of the client's needs and context—a design problem must be framed (Coyne, 2005). This means that even the gathering of information is nondeterministic, as "the information needed to understand the problem depends upon one's idea for solving it" (Rittel & Webber, 1973, p. 161). When working in a team this can prove to be even more challenging, as each designer brings his or her own experiences and interests into individual understanding of the problem (Hey, Yu, & Agogino, 2008; Reiter-Palmon, 2009). As a team designs, its members iteratively formulate and reformulate the problem (Cross, 2001). Sometimes this occurs as a means to render an intractable problem into solvable subproblems (Reitman, 1964), but the degree to which they do so depends on their tolerance for ambiguity, their experience, and the resources available, all of which makes the process highly contingent (Schrader, Riggs, & Smith, 1993).

Part of taking ownership of a problem involves iterative problem structuring (Newell & Simon, 1972; Restrepo & Christiaans, 2003) or problem setting (Schön, 1987)—setting boundaries or delimiting aspects of the problem space. This activity is often in response to identified needs (Hey et al., 2008). We call out the information–gathering process of identifying needs as specifically belonging to problem framing; identifying needs involves perspectival shifts and developing empathy for those who use the designed object. Potential design decisions and tentative solutions are evaluated by considering how the design might address those needs (Griffin & Hauser, 1993). This creates an opportunity for learning, because such evaluation involves reflecting on and critically evaluating design decisions against one's understanding of the problem space, reframing it as needed. This highlights that problems can be reframed even late in the process of design if designers realize that their solution is not meeting identified needs or is violating constraints.

Thus, although problem framing has been viewed as front-end activities that precede problem solving (Basadur et al., 1982; Kvan & Gao, 2006; Woodhall, 2011), solving ill-structured problems is an iterative process in which problem framing oscillates with problem solving (Dorst & Cross,

2001; Rittel & Webber, 1973; Tracy, 2005). This oscillation is visible in experienced designers, who are adept at switching between framing and solving activities (Atman, Chimka, Bursic, & Nachtmann, 1999). The problem to be solved coevolves with the solution (Dorst & Cross, 2001), meaning that the designer must frame and reframe the problem. As the designer learns more about the problem, "every question [that is] asking for additional information depends upon the understanding of the problem—and its resolution—at that time. Problem understanding and problem resolution are concomitant to each other" (Rittel & Webber, 1973, p. 161). Thus, we see problem framing as threaded throughout design process.

We therefore argue that problem framing is an agentive process of finding information purposefully and through perspective shifts, evaluating tentative design decisions against their potential to address identified needs, and managing problem ambiguity by iteratively restructuring problems. Thus, simply transferring problem framing activities such as information gathering, ideation, and evaluation into school settings does not ensure that students will take ownership of the problems they are framing. Information gathering might be reduced to reading a textbook or searching online, often with a purpose supplied by the teacher. This reduces the need for problem framing and thereby the opportunities for learning through problem framing. Likewise, idea generation can be a hoop to jump through, with students first arriving at the idea they wish to pursue, then spending time generating flawed versions of this idea (Boling & Smith, 2014). Even when students are asked to take some ownership of the problem, they seldom have opportunities to iterate on its framing. We next consider some of the barriers that prevent students from having opportunities to participate in problem framing.

Navigating Barriers to Problem Framing in Classrooms

Supporting students to frame problems requires a "willingness to relinquish tight control over students and . . . the transfer of a large amount of responsibility for learning to students" (Roth & Bowen, 1993, p. 198). This can feel risky to teachers (Marx et al., 1997; Scott, 1994), yet navigating this ambiguity is central to maintaining student-centered pedagogical approaches (Grant & Hill, 2006) and to preparing designers who are capable of framing problems. Only learning to solve well-structured problems does not transfer naturally to solving ill-structured problems (Jonassen, Strobel, & Lee, 2006), though the converse may be true (Kapur, 2015). Less experienced designers often don't recognize the need to frame the problem, in part because of the emphasis on well-structured problem solving, which dominates the majority of their classroom experiences (Crismond & Adams, 2012). When asked

to frame their own problems, young students initially frame their problems as well-structured problems (Lowrie, 2002). Inexperienced designers tend to jump quickly to solutions, treating design problems as well-structured (Christiaans & Dorst, 1992; Rowland, 1992). Thus, problem framing can be challenging for students who are not used to this type of activity (Franske, 2009). Four primary approaches to supporting problem framing have been investigated previously: providing students with examples of open-ended problems and then asking them to pose their own, prompting students to restate the problem and consider multiple perspectives, scaffolding students to pose questions about the problem, and helping students connect personally with the problem.

Helping students understand that some problems have multiple possible answers can support them to frame more open-ended problems (Lowrie, 2002); for instance, after being exposed to open-ended mathematics problems and being asked to consider multiple ways to solve problems, half of the young students could pose questions such as "How long would it take for me to tie your shoes up?" and "What would a seesaw look like if you sat on one end I sat on the other end?" (p. 358). Other students were described as less open to taking risks and only reproduced well-structured problems they had previously been exposed to (Lowrie, 2002). Therefore, additional supports may be needed.

One approach to scaffolding students to consider the problem more carefully is to prompt them to restate the problem prior to solving it. In a laboratory study that used this approach, students who were also given discrepant information explored the problem from more points of view (Reiter-Palmon, Mumford, O'Connor Boes, & Runco, 1997). Although conducted as a brief laboratory task, this is not so different from the need to consider potential trade-offs and differing perspectives in an authentic design task. Thus, ensuring that students have access to multiple points of view about a problem may help them to frame the problem.

Another approach to supporting students in framing the problem was investigated in a quasi-experimental study conducted in intact classrooms; students were positioned as members of an environmental firm helping a client solve legal issues related to pollution (Zydney, 2008). All students, including those in a control condition, were tasked with planning how to solve the problem, including describing the problem and identifying questions and resources needed. Students in one condition were given an organizational tool that prompted them with eight questions to help organize their planning, such as "What are your client's objectives and goals?" (p. 366). Students in another condition were given a higher-order thinking tool that asked for a "status report" by

posing three questions about their initial impression of the problem, how their ideas changed after learning more, and what they still needed to learn. A third condition had access to both the organization tool and the higher-order thinking tool. Students who used the organization tool asked more questions about the problem and had better understanding of the problem; in contrast, students who did not have this tool asked more questions about the solution, suggesting a solution-focused approach (Zydney, 2008). Thus, scaffolds that help students ask questions about the problem may be useful in supporting them to frame the problem.

Qualitative studies have suggested that helping students connect the problem to their personal interests is valuable but may not help them identify a problem narrowly or specifically enough to investigate further (Ritchie, 2009). One approach to dealing with this is to provide additional framing or problem context, and this has been shown to help students feel ownership of the problems (Roth & Bowen, 1993). However, this does not necessarily provide students with the skills to frame their own problems. Researchers have speculated that providing problem contexts that have value beyond the classroom walls, with authentic clients, could help (LaBanca & Ritchie, 2011; Ritchie, 2009), but this is not well backed by research, at least in relation to supporting problem framing; this is the purpose of the current study.

Research Purpose and Questions

Our research aims to investigate how teachers positioned students as designers responsible for framing an authentic problem and how their students took this up. We investigate this in a setting that allowed us to consider extended problem framing that occurred over multiple weeks in which students were asked to identify and address client needs. To guide our investigation, we pose orienting research questions:

- How did teachers shift the locus of control to the students?
- To what extent did students identify needs, gather information with purpose, generate ideas, and evaluate those ideas based on identified needs?
- In what ways did students reframe the problem?
- Were previously investigated supports—providing students with examples of open-ended problems and then asking them to pose their own, prompting students to restate the problem and consider multiple perspectives, scaffolding students to pose questions about the problem, and helping students connect personally with the problem—employed, and were these scaffolds helpful?

Methods

Project-Based Learning Model

The PBL model employed by the study site is informed by the Buck Institute for Education and industry partners, meaning that projects are aligned to architecture, construction, and engineering practices. Because of this industry lens, most of the projects involve designing something, often for a client. This is not so different from many published accounts of project-based science, in which designing is used to motivate the need for scientific inquiry; for instance, students submitted model rocket designs to NASA to help create a need to know (Barron et al., 1998; Petrosino, 1998). At this school, teachers design projects, often with support from industry partners. We present a detailed account of this design process elsewhere (Svihla et al., 2016). As they design projects, they pay particular attention to creating access points for students and making sure the project is relevant to students' lives while being authentically connected to the industry practices. Their driving questions are therefore typically crafted to pique students' interest. In the project presented here, the driving question "Where are you gonna sleep tonight?" additionally helped students shift their perspective, placing themselves in the role of a person who is homeless. The project content focused on English-language arts (grades 9–12), economics, and U.S. history.

Students attend a morning and an afternoon project block, with blocks lasting 135 minutes. Typical instruction involves brief whole-group instruction followed by work time, peppered with catch-and-release, ending in a debrief session. Projects culminate in a public exhibition of their work attended by community and industry members.

In the project we investigated, the problem as initially framed was ill-structured in that students were to design a temporary shelter that met the needs of their specific client, using waste and found materials. Because of the range of clients (some living alone, others as families), their varied needs (e.g., some had disabilities, and clients presented a range of needs in terms of being warm, secure, well camouflaged, etc.), and the found materials, there were many potential design solutions, meaning that the problem did not have an a priori, correct, knowable solution. In fact, given the broad range of possible found materials, the project, as originally proposed, had a great deal of creative potential.

Theoretical Stance

This research was conducted in a setting that is grounded in constructionism (Papert & Harel, 1991); thus, learning was viewed as supported through engaged, meaningful activity in which students frame problems and construct designs that are sharable with those beyond the class. As Papert observed, such learning occurs "in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" (p. 1). Thus, such learning is not synonymous with making but instead suggests that students pursue problems they find meaningful and present their learning in some publicly sharable format.

As researchers, we likewise view learning through a constructionist lens and selected this particular site to conduct research because it exemplified constructionist learning. As constructionists, we also see learning as a fundamentally social, interactional process (Bransford, Brown, & Cocking, 2000; Kuhl, 2004; Vygotsky, 1978) that occurs over time, through participation of various types (Lave & Wenger, 1991), and situated in contexts. This stance informed our research design, suggesting the need to examine learning as interactional, occurring over time, through participatory approaches that would allow the development of emic understandings.

Research Design and Data Collection

Data were collected as part of a larger long-term participant observation research project that documented multiple projects taught at the school, along with other school-specific practices. The current study focuses on one project, Waste Land II, a nine-week, interdisciplinary and multi-grade project.

Data collection included field notes, photographs, audio and video recordings, interviews, and the collection of artifacts of work. Every project meeting was documented, along with many conversations about project planning and assessing student work. The data were collected with an ethnographic stance, using participant observation (Atkinson & Hammersley, 1994; DeWalt & DeWalt, 2010; Jorgensen, 1989). The first author (Dr. S) had developed a relationship with the school over three years and was embedded in the school daily for the duration of the project planning and implementation. In order to gain a more insider perspective, the first author cotaught the project and collected field notes, with a few days spent primarily teaching. On such days, field notes were taken by project assistants who had completed a qualitative research methods course and had been trained by the first author. The field notes were collected using a template with places to note date, time, researcher's name, overview of the data collected, list of related files, and a reflection, in addition to space for field notes. Because of the volume of data collected, field notes focused more on creating a record of turns of talk than is typical for field notes, resulting in a rough transcript of the project, particularly during class discussions and whole-group presentations. Actions,

observations, and interpretive statements within the field notes were noted systematically using double parentheses, with interpretive statements called out with "I wonder," "I think," or similar sentence starters. All data were entered into a database created for the project using FileMaker Pro. As they were entered into the database, they were tagged with specific analytic foci, which included problem framing, ideation, problem solving, assessment, etc., to facilitate data selection and reuse.

Data collection began following Institutional Review Board approval. The participants were teachers (Mr. W, Mr. J) and their students (*n* = 27) at a New Mexican charter school whose mission is to serve those who have not been well served by traditional schooling. Mr. W, who is certified to teach social studies and Spanish, has been teaching for 14 years, with 2 years of experience in project-based settings. He brings his 15 years of practicing law into his teaching. Mr. J, who is a certified special education teacher, joined the school after completing his student teaching at the school; he has three years of teaching experience and 14 years of experience in construction, which he brings into his teaching. The school provides fives weeks of professional development on PBL each year as well as two hours of professional development each week.

The students were predominantly Latino, male, off track to graduation, and qualified for free lunch. We focus on three students, Benjamin, Andre, and Ivan; these students were selected as follows: we first opted for students who provided full consent (including video, not just audio). We then eliminated students who enrolled in the project late or who had consistently poor attendance. We included Benjamin because he was so visibly and vocally engaged in the project at the beginning, meaning that we had a lot of data about his participation. We next aimed to select students from different social cliques and who represented a range of participation styles but were seen as disengaged at some point during the project, as these students are seen as the *least likely* to take ownership of framing the problem. All three students received special education services; the school serves a larger percentage of such students compared to traditional schools because of its mission. To avoid inadvertently revealing a student's identity, we do not make note of accommodations or services that affected how students engaged in specific tasks.

Benjamin was initially very engaged in class discussions, responding out loud to almost every question and posing many of his own questions. Despite this, he completed little written project work. He struggled with the project content apparently because it was close to his own experiences; his family had experienced food and housing insecurity when he was young but had found security in a family-owned cleaning business. Benjamin stopped coming to Waste Land II two weeks before the end of the project and did not attend the exhibition.

Andre was initially commonly late to class, sometimes missing as much as the first hour of class, and sitting with a group of students who were often engaged in social activities rather than the project. Despite this, he did his work and became very engaged in Waste Land II after the first few weeks. He began more consistently arriving on time, explaining that he found the problem to be important and meaningful. His exhibition was thoughtful and complete.

Ivan was part of a clique of young men who systematically appeared disengaged. They would commonly slip out of projects and congregate together. There were three members of this clique in Waste Land II. Typically, they spent much of the class period gazing at their smartphones and sometimes engaging in conversation with a teacher. Ivan seldom missed class and was consistently on time. At the final exhibition, despite his apparent disengagement, he was able to provide answers to challenging questions from industry and community members, even though he had little work to display.

Data Selection and Analysis

The initial data corpus covered all data associated with the project and included approximately 180 pages of field notes, 80 hours of audio/video records, and 500 photos. We selected data from this corpus, guided first by our analysis of intended and enacted project activities. All project activities were classified as primarily intending to accomplish one of five stages of designing (Table 1 and Figure 1, next two pages). The particular design stages were derived from a design process model shared with the students, with the particular stage names aligned to the terms used in this study (e.g., "Define the problem" was renamed "problem framing"). Figure 1 depicts an agile start to design in the first six days of the project; the activities were brief, with many lasting less than one project period. This allowed students to iterate through a design cycle quickly and set up a need-to-know. Setting up a need-to-know is a common approach in PBL. It helps students become invested in learning and directs their search for information, in this case about homelessness. This fed into several weeks of longer periods of information gathering, ideation, and solution generation. The project culminated in two weeks of solution-focused work, interleaved with opportunities to evaluate solutions in light of identified needs.

Although we classified the activities of Waste Land II in terms of their primary purpose, we noted that many activities actually provided opportunities for students to frame and reframe the problem. Thus, our data selection involved reviewing all field notes in the corpus for episodes of problem framing. We included episodes intended to support problem framing as well as episodes in which it occurred as students worked to understand the problem. When reviewing field

Table 1. Categorization of activities by intended design stage.

Design Stage	Description: Activities intended to:	Example Activities
Problem framing	provide an initial framing, orient students to the problem framing, or support students to frame the problem	Project launch positioned the project as being about designing temporary shelters for homeless people; students assessed needs of homeless people in their city.
Gather information	build student knowledge and understanding of the problem	Students completed crossword puzzles connected to newspaper articles about laws affecting homeless people; they researched solutions to homelessness.
Ideation	help students consider different points of view and ways to meet identified needs	Students created worst-solution sketches as part of a wrong theory activity.
Develop solutions	support students to develop tentative and improved solutions to identified needs	Students created models of temporary shelters; they wrote letters to representatives about solutions to homelessness.
Evaluation	provide students with feedback on how well their solutions responded to identified needs	Students gave each other feedback on their models; they presented their solutions to community members at exhibitions.

notes, we attended to episodes in which we recorded students doing the following types of activities:

- describing their design ideas in written, sketch, or model form;
- brainstorming or ideating;
- gathering information from clients, the Internet, or guest speakers;
- making decisions or choices about their design ideas;
- posing questions about the design problem; and
- making statements about the design problem.

Because field notes were indexed to audio and/or video records we could transcribe episodes selected, and we supplemented the transcripts with artifacts of participation to more richly capture the interaction. This included photos of student work, whiteboards, and screen captures from videos.

We analyzed transcripts using interaction analysis (Jordan & Henderson, 1995). Unlike many forms of qualitative analysis, interaction analysis does not involve application of a coding scheme; instead, analytic foci are used to iteratively view and interpret data. Traditionally, this includes the structure of events, participation structures, the spatial organization of activity, and artifacts. We considered these in light of the design activities we described in our literature

review, specifically focusing on how these played out as students framed the problem as they gathered information, generated ideas, or evaluated their ideas. We also attended to previously identified problem framing supports, including providing students with examples of open-ended problems and then asking them to pose their own, prompting students to restate the problem and/or consider multiple perspectives, scaffolding students to pose questions about the problem, helping students connect personally with the problem, and providing authentic context.

Analysis of the structure of events means that interaction occurs over time, with beginnings and endings and with segments, all of which can be recognized by participants (Jordan & Henderson, 1995). For instance, the project as a whole and each project period have a clear beginning and ending, though the beginning and ending of an individual student's participation may vary. Project work time is easily segmented by typical instructional sequences common to the school but also by completion of specific tasks (e.g., drawing a possible design), which again can vary by participant. Our first-pass analysis provided an overview of activity segmentation (Figure 1, next page) and made visible a macro-level shift from agile design in the first few days to longer periods of focused work on particular design activities, culminating in longer

The first 9 days of Waste Land II

Where are you gonna sleep tonight? Needs — Homelessness facts — Design process — Needs — Needs — Guest speaker — Interview homeless people — Tent city reading — Needs

- Problem framing
- Gather information
- Ideation
- Develop solutions
- Evaluation

Profile — Sketch — Wrong Theory — Profile Present — Sketch Present — Build models — Critique — Interview prep

Days 10-18 of Waste Land II

Analysis of interviews — Existing designs — Laws — Jurisdiction — Existing designs

- Problem framing
- Gather information
- Ideation
- Develop solutions
- Evaluation

Sketch — Sketch — Sketch

Days 19-27 of Waste Land II

Insulation — Long term solutions — Political philosophies — Long term solutions

- Problem framing
- Gather information
- Ideation
- Develop solutions
- Evaluation

Sketch — Sketch — Long term solutions

Days 28-35 of Waste Land II

Economics of slums

- Problem framing
- Gather information
- Ideation
- Develop solutions
- Evaluation

Long term solutions & slums — Teacher feedback — Final designs — Teacher feedback — Exhibitions

Figure 1. Timeline of the Waste Land II project, with activities classified by design stage. Each column represents one project period, with subcolumns representing individual weeks.

periods of evaluation. On the meso-level time scale, we analyzed how students engaged with the tasks over minutes to days, and on the micro-level time scale we considered how they engaged conversationally and interactionally, moment by moment and/or turn by turn.

In interaction analysis, participation structures help reveal whether "individuals share a common task orientation and attentional focus" (Jordan & Henderson, 1995, p. 67). Here, we considered whether common focus was shared across students as well as across teachers and students. Likewise, the spatial organization of activity and analysis of artifacts and documents can help reveal ownership by considering who made specific artifacts, who can modify them, who can display them, where they are located spatially, and who has access to them. In traditional classrooms, whiteboards, chalkboards, and the like are the territory of teachers; students create work for teachers, who may modify the work, marking it to denote changes needed or judgments passed.

We reviewed data during research lab meetings, following events over time and across participants and considering evidence of ownership from the spatial organization of activity and the analysis of artifacts. We present vignettes that are either representative of the data corpus or that are critical moments; such critical moments, though idiosyncratic, can be influential and deserve consideration for their role in learning. Within the vignettes, we present transcripts in which we have used a few conventions to better convey the tone and cadence of conversations:

- A WORD in all capital letters indicates that it was spoken in a loud voice. Capital letters used WITHin a word indicate that a syllable was spoken in a loud voice but the rest of the word was not.
- A wo:::rd with colons indicates that the sound was drawn out.
- // indicates overlapping talk.
- (.) indicates a noticeable pause.
- Ellipses indicate an omission or edit for clarity.
- Underlining indicates that a word was emphasized somewhat, through moderation of tone or cadence, but not noticeably louder, softer, or more drawn out.
- Punctuation is used to indicate tone; thus, a question mark is only used when the tone conveyed a question, regardless of grammar.

Results

We present vignettes from the first six days of the project to highlight both the regularities and critical moments we identified related to teachers shifting the locus of control to the students. In the first vignette, the teachers positioned students as designers. This supported the students to start taking ownership of the problem. We present this positioning and then highlight how the teachers struggled to follow through on this positioning; for instance, as students took ownership, they reframed the problem to be larger than the teachers had envisioned. We follow the teachers in their interactions with Benjamin, Ivan, and Andre across vignettes where their positioning as designers is visible and where the students take ownership of the problem. Our purpose is not to follow the project to designed solutions but rather to show tensions in transferring ownership of the problem to the students and how doing so opened opportunities for students to learn.

Positioning Students as Designers and Scaffolding an Iterative, Client-Driven Design Process

Mr. W introduced the name of the project and asked students what they thought the project would be about. Students guessed that the project would be about building with waste materials. Mr. W then explained that they would be "designing stuff for people who maybe can't afford to buy anything, right? Who have no resources or very limited resources. How can they build something with stuff that they can just find?" The teachers then positioned the students as designers:

Mr. W: What do you gotta think of as a designer?

This initial positioning was somewhat implicit, but the teachers then followed this question with scaffolding on how to begin framing the problem by thinking about their client:

Mr. W: Who are you designing for? A homeless person, right? So really, what we are looking at here//

Mr. J: // So, that's your client guys. So, who is the client, right? You can't sit down and—You can start designing something, but until you know WHO you are building that for, and what their SPEcific needs are, you're gonna probably be pretty far off the mark as far as what your end product looks like, right? If you know these questions, maybe come up with questions to begin with, right, and use that to inform the design you create, what do you guys think? Is that gonna end up being a better design, or is your design gonna be worse?

Mr. W: So that means that step number one in this process is gonna be what we call a needs assessment.

The teachers emphasized the importance of understanding client needs as a means to guiding design work. They then prepared the students for conducting a needs assessment with clients by having them craft a profile of a hypothetical homeless person. This helped them begin to frame the problem but led to a broader framing than the teachers had envisioned. Ivan arrived late but near the end of class

Figure 2. Andre's description of his hypothetical client's needs.

recorded his hypothetical client's needs as "Food Shelter-warmth Clothing Basic Helth [*sic*] Shopping cart Knife Fire." Likewise, Andre referenced a place to stay, health concerns, and other services (Figure 2). Benjamin did not complete the assignment and shared with Dr. S that he didn't care about homeless people.

Because the teachers envisioned a narrower problem focused on temporary shelter design, they introduced the idea of iteration and staying in *sketch mode.*

Mr. J: So, you guys, <u>rough</u> sketches, right. Don't make this perfect, because it's gonna go through a lot of transition, and updating, and, and using each others' input, as well as what we get from whoever it is we interview to make it different, make it better, right? So don't spend all your time focusing on one aspect, or just one shelter, alright?

Mr. W: Make it rough. . . . When people put too much time into their first idea, then they're upset when people say "I don't like it. <u>Change</u> it." . . . What's the likelihood that your first idea is the best idea, right?

Although the teachers brought the idea of client into their instruction, they did so in a somewhat vague manner,

"whoever it is we interview"; this paired with making hypothetical client profiles signaled to students implicitly that there was not a specific client at this point. This allowed the teachers to emphasize the importance of iteration in designing, an important point, as many of the projects at the school included designing, but few included iteration.

Most students' initial sketches for temporary shelters were cardboard boxes; as they were pushed to sketch multiple ideas, other ideas emerged (Figure 3). None of the focal students completed the initial sketches. Benjamin, however, talked about just finding a box, and Mr. W shared Andre's design idea at the end of class as they discussed how to meet needs: "Andre was talking about, uh, foam boards. It's a great idea, you know, like insulating foam board, right. Good insulation, but are homeless people gonna be able to find those laying around reliably?" Ivan, who had arrived late and missed the initial project launch, remained disengaged; he sat at the back of class, chatting with friends, though Mr. J introduced the project to him. The level of participation from the focal students suggested that they were not terribly excited by the project as posed to them.

On the second day of the project, Mr. W began by reminding the students of the driving question and their goals:

Mr. W: We started off yesterday by, um, talking about how this project is gonna go, and one of the first things we're gonna do—and we started yesterday—is we started to design a shelter, right. A shelter that a homeless person could possibly sleep in, that would cost him or her zero dollars and zero cents, that can be manufactured out of waste products, right. Meaning, meaning stuff that we can find that nobody would have a problem, if we took it, right. That's our design challenge, and we, we started really by talking about how, before you design you have to stop and think, who are you designing this for, right?
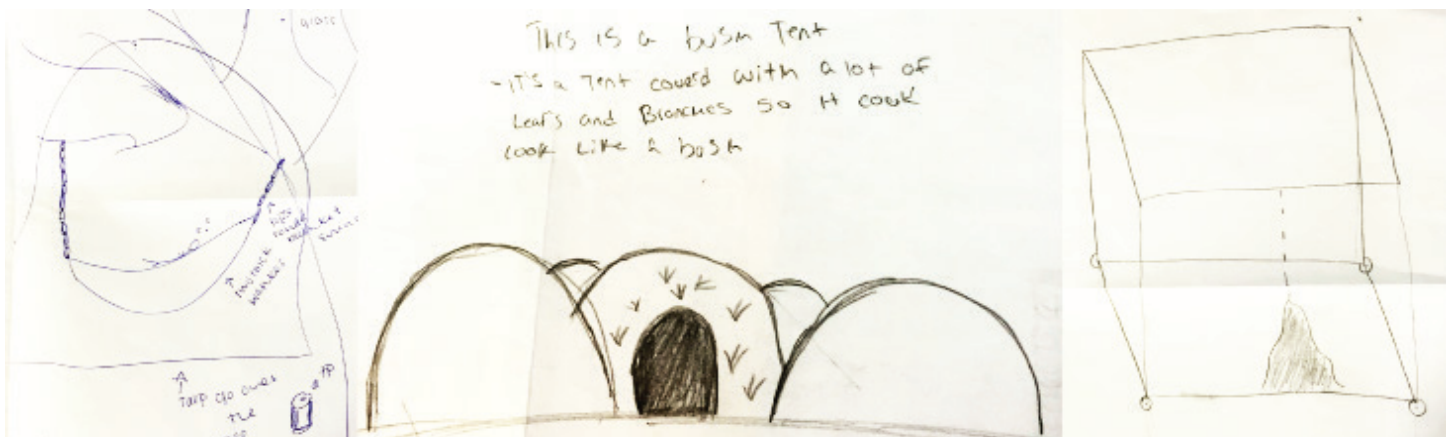

Figure 3. Students' initial sketches (hammock, bush tent, wheeled box).

Students then worked on a crossword puzzle to help them develop familiarity with relevant vocabulary and to introduce facts about homelessness in New Mexico. Because many students had seemed stuck in terms of coming up with design ideas in the previous class, Dr. S introduced an ideation technique based on wrong theory (Dadich, 2014) once students had completed the crossword puzzle:

Dr. S: How many of you sometimes try to come up with an idea and you get stuck? You can't come up with any good ideas.

Benjamin: I think we all have

Dr. S: Yeah, everyone. This happens in design. So what designers have found is—so sometimes when you come up with the worst possible idea, you really try to get a bad idea out there, that it just gets the, gets the ideas flowing and you start coming up with better ideas. Yeah, so your goal, for the next little bit, in your groups, is to come up with the worst possible solution you can imagine. And then you're gonna present these. And you're not gonna have a lot of time, so you gotta really hit the ground running on this. . . . I want you to convince us why your idea is the worst.

Mr. J: . . . We're gonna vote, and see whose idea was the absolute worst. Sound fair?

Benjamin: Yeah.

Mr. J: So, no hurt feelings. No people getting upset because the goal here is to have the worst ide—design.

Mr. W: Yeah 'cause think about it, like, an insult would be, I don't know, "Actually, that is a pretty good idea," right. . . . We talked about needs assessment, so one way to approach this is like, "What do they NOT need?" Right. That might be one way to approach it. Right. Or how can I make sure that I don't meet their needs.

Students engaged in the assignment reluctantly in the first minute or two and then enthusiastically. Benjamin's group came up with many ideas and volunteered to present first. Benjamin explained that "my ideas are THE worst ideas . . . because I really thought about what's gonna hurt them in the long run." He shared their idea of a "tequila water dispenser" and "a building with walls but no roof. . . . The walls are gonna be made of glass. Glass-walled house, which would provide no privacy." Ivan, who had initially sat at the back of the room, came to the front during the activity. He was visibly pleased to have his group's idea celebrated as one of

the worst: "either you live in a flaming car or you can die," to which Benjamin responded, "That's horrible. That's the ultimate." Andre's idea was "four branches and a hefty bag," which, when he realized it was a comparatively *good* idea, he amended with "it's located on side of mountain. It's really windy." Students were then turned loose to return to coming up with ideas that would meet their clients' needs. Their new designs were no longer based on boxes but instead represented diverse approaches to temporary shelters that generally met at least one need, such as keeping someone out of the sun or rain.

At the beginning of the third day, as a way to help the students understand the role of assessing needs in problem framing, the teachers asked students to compare the hypothetical profiles they had created to the facts about homelessness they had learned the previous day. They hoped to prompt understanding of general versus specific needs. Ivan began the assignment, writing "In general, the homeless population. The homeless is 40 to 60 years of age. My specific client is 45 years of age" but did not complete the assignment. Benjamin engaged with the assignment, talking to the teachers about his ideas, but did not write them down. Andre shared his comparison aloud:

Andre: My fictional homeless friend is [a] 32-year-old veteran that was brought back home traumatized from war. He was prescribed with some strong meds to keep him calm. After a while taking his medication, and witnessing its effects, he began to have an addiction. I say Bill has a same story as many other homeless veterans in general.

The teachers then provided students with a design process model (Figure 4, next page); although the model depicts design process as a sequence, Mr. J explained that the designer does not "have to move in that specific order," thereby problematizing the model for the students.

After introducing the design process model, Mr. J explained he wanted the students to frame the problem:

Mr. J: So, what we're gonna do right now as a group, is define our problem, alright. We kinda know the whole purpose of what we're trying to do here, but I want everybody to be on the same page, and I could tell you what the problem is, but that doesn't include you guys and more importantly it doesn't give you guys the opportunity to contribute and say, "No, I think this is the problem, or I think we should word it that way." So what we need to do, as a group, here, is collaboratively come up with a specific problem that we are trying to address by building these homeless shelters. So someone start shouting something out. What's the problem
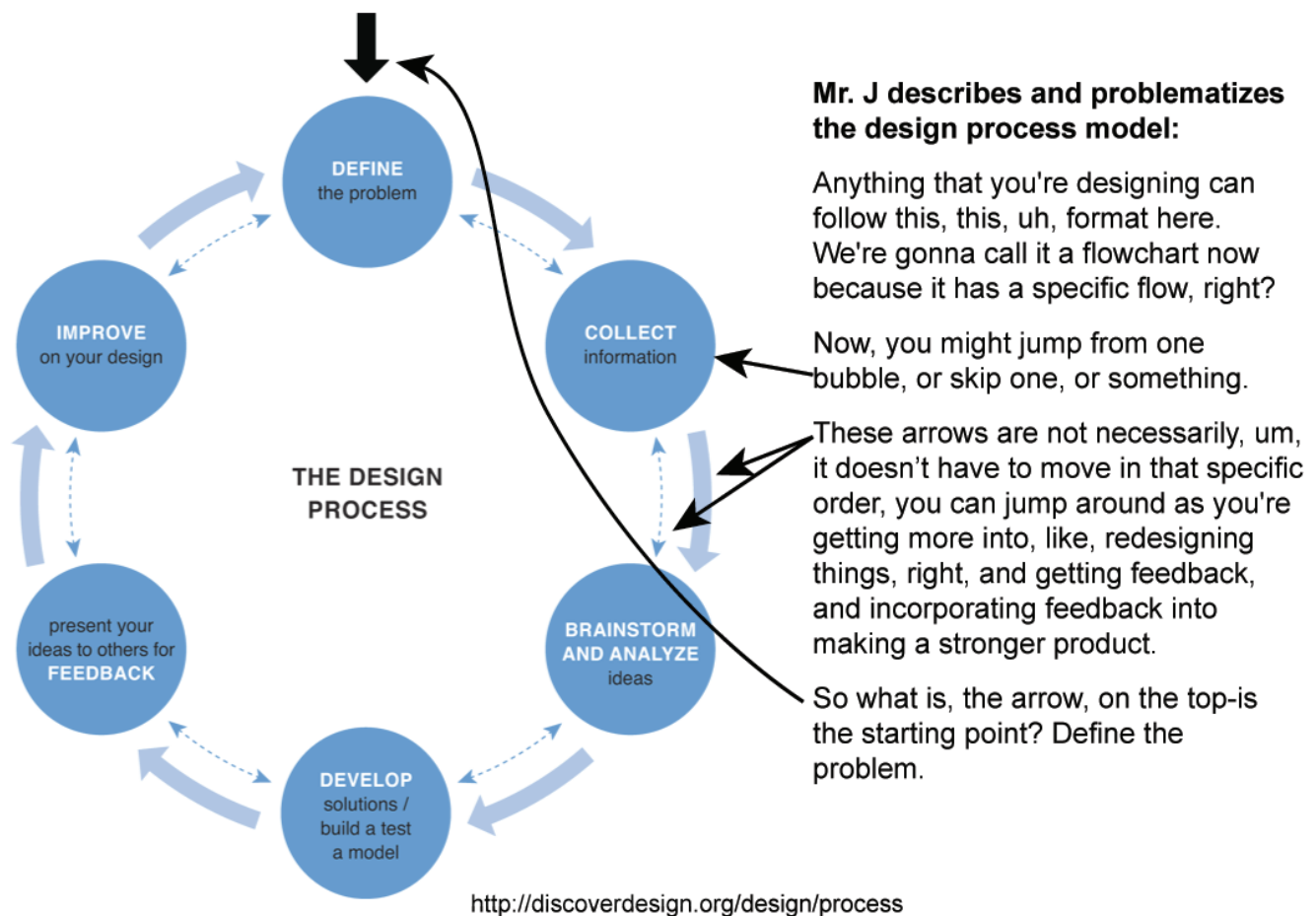
Figure 4. The design process model presented to the students and Mr. J's initial explanation of it.

that we are trying to fix right now? What are we trying to solve?

Benjamin: I'm just guessing here, but homelessness.

Mr. J: Homelessness. Alright. So are we trying to solve homelessness, in general?

Benjamin: No, we're trying to help them.

Mr. J: We're trying to help the homeless.

Benjamin: Living accommodations.

Mr. J: Right, living accommodations.

The majority of students who recorded this in their notebooks listed the problem as homelessness. Students' framing of the problem continued to be broader than the teachers had envisioned. Although Mr. J explained that designers frame problems and that the students were designers, when

Benjamin framed the problem as "homelessness," Mr. J pushed back on this, trying to bring him back to the narrower problem of designing temporary shelters. To further reinforce the idea that they would design temporary shelters for homeless clients, the next two days were spent creating models. All focal students created models (Figure 5), but several models, including Benjamin's, addressed a broad range of needs beyond temporary shelter, and Ivan's listed "food water shelter" next to his model. When they began gathering information on the sixth project day, the division between the teachers' and students' framings of the problem became very clear.

In contrast to the kind of information gathering commonly observed in schools, where students are typically apathetic to the process of locating "enough" sources as prescribed, gathering information for design does not have a stopping rule. This type of information gathering aligns to what was observed once the students took ownership of the problem. Little of the information they sought related to the initial framing from the teachers as a problem focused on temporary shelter. Instead, the students pursued their curiosity,
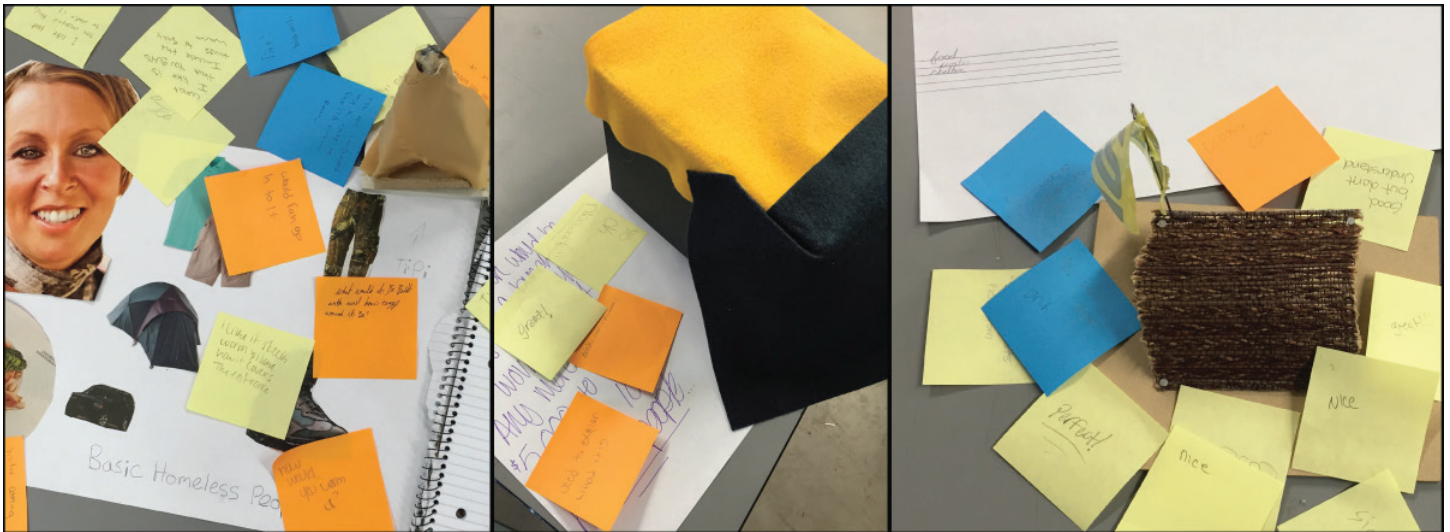
Figure 5. Students' initial models of temporary shelters, with Benjamin's model on the left, Andre's model in the middle, and Ivan's model on the right

familiarity, and empathy with the broader problem of homelessness. Because this bigger issue was one they connected to in various ways, they learned as they gathered information. For instance, on the sixth day of the project, a guest speaker from a local day shelter presented to the students. Benjamin asked the guest speaker 121 questions, and she answered his questions patiently and seriously. For instance, he asked:

- "You said most of—the majority of the homeless people have mental illness. Do you guys, uh, rehabilitate them or? Is that your job? Or, how do you know they have a mental illness?"
- "Is there like a doctor who works with you guys to diagnose these individuals or is it something, like, based on how? Or do you GUESS? I don't—I don't know. I'm just curious how do you know that."
- "Do you give them food?"
- "Do you work with them every day?"
- "Is there, like, a needle exchange?"
- "If they have, like, you said something about a criminal record—you guys don't turn anybody down, right? Violent? Or you accept anyone?"
- "Do you guys find 'em homes? Do you have, like, uh, do? You get them homes, right? You said that. How do they pay for those homes? How do they pay utilities?"
- "Do you guys also give 'em, like clothing?"
- "Do you give them bus passes?"

Although Benjamin asked the majority of questions (Andre asked if they provided laundry detergent for them to wash their clothes, and another student asked if their clients could bring pets or if they served families), most students attended to the guest's answers and took notes. The students

were surprised, for instance, to find out that people could be arrested for sleeping on the street. Benjamin expressed this out loud: "Oh, so you can't just sleep wherever you want?" Many students looked up, startled at this information. In the midst of this, Mr. W attempted to steer the conversation back to the original framing:

> Mr. W: We're hoping to focus on, you know, are there solutions that could help them be warmer, drier, you know, <u>at night</u>, right? Not building a shelter. Not changing the government. Kind of immediate solutions.

In his last statement, Mr. W urged everyone to think about temporary solutions, such as the temporary shelters the teachers envisioned. Benjamin connected this to the information that it was illegal to sleep outside:

> Benjamin: So, um, like, you said, they can't just sleep wherever they want, right, and sometimes—on private property or parks or public? I don't know. They get kicked out? Where CAN they sleep? WHERE can they? Is there an actual place where, um? Like, do you guys give them, like, uh, advice so to speak? Like, "you guys can sleep on this side of town, don't—avoid this side of town."

As Benjamin wrestled with this, he struggled to make sense of why there would not be enough beds for them and yet it would be illegal for them to sleep on the street. His struggle is visible in his fragmented speech:

> Benjamin: So, why don't they do something about? They see that it's? Why don't they? They have shelters. They know that they need, that sometimes? They see the limits. Where do they put them? I don't understand that. . . . They can't just be forgotten.

The guest responded that she was likewise frustrated by this situation and explained a bit more of its complexity. After the guest left, the students spent time preparing questions to ask the clients of the day shelter. Ivan primarily focused on how to interview his client: "1. Basic introduction. 2. Ask non-personal question. 3. Lead to more personal info." Andre had a longer list of interview ideas that he jotted down as the guest spoke: "1. Is it hard for you to get a job? 2. Where do you sleep, if you don't mind me asking? 3. Do you have family here? 4. Do you have many friends?" After hearing the clients might be hesitant to answer some questions and that having a friendly conversation would be a good way to begin the interviews, Andre added the following: "I will first let him know my name and ask him how his day has been." And he added new questions: "What is your motivation that keeps you going? What gives you the strength to accomplish your goals?" He further explained that he was most "interested in learning about [the client's] struggles with life."

These vignettes, from early in the project, show how students began to take ownership of the problem and how, even though the teachers wanted to support this, it was initially a tension and something they resisted. The students consistently framed the problem more broadly as homelessness, not just where a person could sleep at night if he or she was homeless.

The guest speaker presented a pivotal idea: she suggested that one way to help organizations such as hers was to write letters to representatives. This seeded the idea that rather than focusing the project on designing temporary shelters, the students could investigate and design solutions to homelessness in New Mexico, communicated to their state representatives through persuasive letters. Ultimately, the teachers decided that this focus could still allow students to study the focal content while pursuing the problem they had claimed ownership of and framed.

Mr. W explained that when designing, he considers "whether or not the topic seems to be something that's provocative for kids." In this case, he felt that the students were "far more interested in, kind of, the social justice issues. They were more interested in that than they were in building something." He reflected how uncommon this was, as at this particular school a common strategy when students seemed to be disinterested or disengaged was to get them to start building. The idea that they seemed more excited at the idea of writing a letter to their representatives than at the idea of building temporary shelters was unexpected for the teachers. Mr. J reflected on this unexpected shift:

> Mr. J: Instead of us just trying to force them on a trajectory, we kind of let their engagement and, and their levels of interest sorta guide the project and we, we, you know, we have the oars, we're at the helm, but they may

be the winds that—that push the sails. . . . Maybe we're the wind and they're at the helm.

This resonates with the oscillation of ownership of the problem framing that was observed.

The varied participation styles of the focal students reflected much about the school context, with many students bringing habits learned from damaging prior experiences in traditional schools. Throughout the project Ivan maintained a disengaged stance. Benjamin's departure from the project was complex. He was clearly engaged, and his participation played a visible role in reframing the problem to focus broadly on homelessness, yet equally as clearly, he struggled with the idea that he might be helping someone get something they didn't deserve. However, he explained his departure as tied to his need to work on completing a required project for graduation. In contrast, Andre connected to the project. Reflecting on his experiences in the project, he explained that "it connected me a lot—personally also—to this project."

Discussion

By positioning students as designers within project-based instruction, students not only have opportunities to frame problems, but they need to actively frame and reframe the problems. We also found that students gathered information, generated ideas, and evaluated those ideas in a purposeful manner because they were given ownership of the problem. We presented vignettes showing how teachers worked to shift the locus of control to their students. They positioned the students as designers, described and problematized a design process model, and asked the students to frame the problem. Despite this clear intent, the teachers struggled to give complete control of the problem over to the students when they realized that the students were reframing the problem not as designing temporary shelters for homeless people but instead as solving homelessness. Initially the teachers resisted, inserting reminders of the project goal as they themselves had framed it. Unlike many of the familiar problem-based teaching strategies, such as revoicing and summarizing (Hmelo-Silver & Barrows, 2006), guiding students to take ownership of problems means releasing a great deal of control. Thus, even the most experienced project-based teachers in our study displayed efforts to redirect students to the problem the teachers had originally framed, despite explicitly wanting students to engage in problem framing.

This shift in problem framing, from charity to social justice, may have been partially cued by the introduction of an activity on facts about homelessness in New Mexico, but we also documented active identification of needs, generation of ideas, and information seeking in support of this framing. Even as

the students drew or built models of temporary shelters, they included details about other needs and solutions, such as food, needle exchanges, and places to store belongings.

We found evidence of specific supports, but these were used in more complex ways than described in previous studies. First, students were provided with an open-ended problem (designing temporary shelters from waste materials) and then were asked to define the problem. Many recorded an open-ended problem ("homelessness") in their notebooks. Students were also scaffolded to pose questions about the problem. They were supported in doing so in the form of questions to ask the guest speaker and interview questions for clients; we see this as extending and integrating prior work on posing questions (Lowrie, 2002; Zydney, 2008) and the role of authentic context (LaBanca & Ritchie, 2011; Ritchie, 2009). Specifically, asking students to pose questions about the problem to an authentic audience supported their framing of the problem. The actual responses provided multiple perspectives and discrepant information, as suggested by prior laboratory studies (Reiter-Palmon et al., 1997). This sometimes surprised the students, such as when they found that people "can't just sleep wherever they want." For the students, this insight may have made the idea of constructing temporary shelters seem less viable and the need to solve homelessness even more urgent. These perspectives may have strengthened their resolve, and ultimately it was the guest speaker's suggestion to write persuasive letters to their representatives that seeded the idea of the format their designs would take.

The problem was authentic and one that students could connect to personally in various ways; some had experienced homelessness or housing insecurity, but all of them saw or interacted with people who were homeless on a nearly daily basis simply because of the location of the school. It was this connection that drove Benjamin toward and then away from the project and drew Andre closer to it. Benjamin strongly influenced the problem framing and actively struggled to make sense of the problem. His departure, as noted earlier, was complex, and because of its complexity, we do not see it as a contraindication to allowing students to frame problems with which they are personally connected, though we do argue for some caution and care when problems might be proximal to students' prior traumatic experiences. Ultimately, Benjamin's engagement resulted in meaningful learning for him and for his classmates. And similar to prior work,

though compelling to many students, the personal connection did not help narrow the problem (Ritchie, 2009).

Problems vary by type, from well-structured to ill-structured. These different problem types provide different opportunities for learning, with design problems producing some of the highest effect sizes (Walker & Leary, 2009). The present study extends this finding to show how ownership of design problems, while challenging to manage, presents abundant opportunities for students to engage in meaningful learning opportunities. The teachers provided what they viewed as an ill-structured problem, complete with clients and instructions about a design process; they encouraged students to begin their design work in "sketch mode," talked about the iterative nature of designing, and problematized the design process model. This set of supports engaged students in taking ownership of and thereby taking responsibility for framing the problems. In taking this ownership, there were myriad opportunities for learning. In this way, designing and learning became inseparable (Collin, 2006).

Limitations

The data presented are deeply contextual; the particular population of students, in this case, is somewhat idiosyncratic. Thus, the supports detailed may not transfer to other settings, particularly those that do not often engage design problems. The particular topic—homelessness—was close to the lives of these students. Many of them had experienced food and housing insecurity. This connects in complex ways to the potential learning opportunities experienced by the students. The particular school has a large social work staff who worked closely with the students, particularly with Benjamin and Ivan. Thus, this same topic, given different students or fewer social supports, would look quite different, including its potential for supporting learning.

Future Research

Further research should contrast the types of learning made available through ill-structured problem framing to the kind of learning that happens in the absence of this type of problem framing. Understanding how to support students to learn through problem framing opens possibilities to better prepare them to learn in less scaffolded real-world settings. Extending this work should also explore other settings and disciplines where ill-structured problem framing leads to rich learning for students.

References

Atkinson, P., & Hammersley, M. (1994). Ethnography and participant observation. In N. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (Vol. 1, pp. 248–261). Thousand Oaks, CA: Sage.

Atman, C. J., Chimka, J., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshman and senior engineering design processes. *Design Studies, 20*(2), 131–152.

Atman, C. J., Yasuhara, K., Adams, R. S., Barker, T., Turns, J., & Rhone, E. (2008). Breadth in problem scoping: A comparison of freshman and senior engineering students. *International Journal of Engineering Education, 24*(2), 234–245.

Barron, B., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A. J., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the Learning Sciences, 7*(3–4), 271–311.

Basadur, M., Graen, G. B., & Green, S. G. (1982). Training in creative problem solving: Effects on ideation and problem finding and solving in an industrial research organization. *Organizational Behavior and Human Performance, 30*(1), 41–70.

Boling, E., & Smith, K. M. (2014). Critical issues in studio pedagogy: Beyond the mystique and down to business. In *Design in Educational Technology* (pp. 37–56). London: Springer.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school* (expanded ed.). Washington, DC: National Academy Press.

Bursic, K. M., & Atman, C. J. (1997). Information gathering: A critical step for quality in the design process. *Quality Management Journal, 4*(4): 60–75.

Christiaans, H. H. C. M., & Dorst, K. (1992). An empirical study into design thinking. In N. Cross, K. Dorst, & N. F. M. Roozenburg (Eds.), *Research in design thinking*. Delft, Netherlands: Delft University Press.

Collin, K. (2006). Connecting work and learning: Design engineers' learning at work. *Journal of Workplace Learning, 18*(7–8), 403–413.

Coyne, R. (2005). Wicked problems revisited. *Design Studies, 26*(1), 5–17.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), 738–797.

Cross, N. (2001). Design cognition: Results from protocol and other empirical studies of design activity. In C. M. Eastman, W. M. McCracken, & W. C. Newstetter (Eds.), *Design knowing and learning: Cognition in design education* (Vol. 5, pp. 79–103). Oxford, UK: Elsevier Science.

Dadich, S. (2014, September 23). Why getting it wrong is the future of design. *Wired,* 126–133.

DeWalt, K. M., & DeWalt, B. R. (2010). *Participant observation: A guide for fieldworkers*. New York: Rowman AltaMira.

Dole, S., Bloom, L., & Kowalske, K. (2016). Transforming pedagogy: Changing perspectives from teacher-centered to learner-centered. *Interdisciplinary Journal of Problem-Based Learning, 10*(1), 1.

Dominick, P. G. (2001). *Tools and tactics of design*. Hoboken, NJ: Wiley.

Dorst, K. (2015). *Frame innovation*. Cambridge, MA: MIT Press.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies, 22*(5), 425–437.

Dorta, T., Perez, E., & Lesage, A. (2008). The ideation gap: Hybrid tools, design flow and practice. *Design Studies, 29*(2), 121–141.

Franske, B. J. (2009). *Engineering problem finding in high school students*. Minneapolis: University of Minnesota.

Grant, M. M., & Hill, J. R. (2006). Weighing the risks with the rewards: Implementing student centered pedagogy within high-stakes testing. In R. G. Lambert & C. J. McCarthy (Eds.), *Understanding teacher stress in an age of accountability*. Greenwich, CT: Information Age.

Griffin, A., & Hauser, J. R. (1993). The voice of the customer. *Marketing Science, 12*(1), 1–27.

Hanauer, D., Frederick, J., Fotinakes, B., & Strobel, S. (2012). Linguistic analysis of project ownership for undergraduate research experiences. *CBE-Life Sciences Education, 11*(4), 378–385.

Hey, J., Yu, J., & Agogino, A. M. (2008). *Design team framing: Paths and principles*. Paper presented at the ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 4.

Homer-Dixon, T. (2000). *The ingenuity gap: How we can solve the problems of the future*. Toronto: Knopf.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development, 45*(1), 65–94.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85.

Jonassen, D. H., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal Of Engineering Education-Washington, 95*(2), 139.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39–103.

Jorgensen, D. L. (1989). *Participant observation.* Wiley Online Library.

Kapur, M. (2015). The preparatory effects of problem solving versus problem posing on learning from instruction. *Learning and Instruction, 39*, 23–31.

Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience, 5*(11), 831–843.

Kvan, T., & Gao, S. (2006). A comparative study of problem framing in multiple settings. In *Design Computing and Cognition '06* (pp. 245–263). London: Springer.

LaBanca, F., & Ritchie, K. C. (2011). The art of scientific ideas: Teaching and learning strategies that promote creative problem finding. *Science Teacher, 78*(8), 48.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lowrie, T. (2002). Designing a framework for problem posing: Young children generating open-ended tasks. *Contemporary Issues in Early Childhood, 3*(3), 354–364.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1997). Enacting project-based science. *Elementary School Journal*, 341–358.

Mergendoller, J. R., Maxwell, N. L., & Bellisimo, Y. (2006). The effectiveness of problem-based instruction: A comparative study of instructional methods and student characteristics. *Interdisciplinary Journal of Problem-Based Learning, 1*(2), 5.

Morozov, A., Kilgore, D., & Atman, C. (2007). Breadth in design problem scoping: Using insights from experts to investigate student processes. Paper presented at the American Society for Engineering Education Annual Conference and Exposition.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). Common core state standards for mathematics. Washington, DC: Authors.

Neeley, W. L., Jr., Lim, K., Zhu, A., & Yang, M. C. (2013). Building fast to think faster: Exploiting rapid prototyping to accelerate ideation during early stage design. Paper presented at the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Newell, A., & Simon, H. A. (1972). *Human problem solving* (Vol. 104). Englewood Cliffs, NJ: Prentice Hall.

Papert, S., & Harel, I. (1991). Situating constructionism. *Constructionism, 36*, 1–11.

Petrosino, A. (1998). The use of reflection and revision in hands-on experimental activities by at-risk children. Unpublished doctoral dissertation, Vanderbilt University, Nashville.

Reiter-Palmon, R. (2009). A dialectic perspective on problem identification and construction. *Industrial and Organizational Psychology, 2*(3), 349–352.

Reiter-Palmon, R., Mumford, M. D., O'Connor Boes, J., & Runco, M. A. (1997). Problem construction and creativity: The role of ability, cue consistency, and active processing. *Creativity Research Journal, 10*(1), 9–23.

Reitman, W. R. (1964). Heuristic decision procedures, open contraints, and the structure of ill-defined problems. In G. Bryan (Ed.), *Human judgements and optimality*. New York: John Wiley.

Restrepo, J., & Christiaans, H. (2003). Problem structuring and information access in design. *Expertise in design*.

Ritchie, K. C. (2009). *The process of problem finding in inquiry education: A focus on students' experiences.* Available at McGill University Library, http://digitool.library.mcgill.ca/webclient/StreamGate?folder_id=0&dvs=1472583495123~297&usePid1=true&usePid2=true

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155–169.

Roth, W. M., & Bowen, G. M. (1993). An investigation of problem framing and solving in a grade 8 open-inquiry science program. *Journal of the Learning Sciences, 3*(2), 165. doi:10.1207/s15327809jls0302_2

Rowland, G. (1992). What do instructional designers actually do? An initial investigation of expert practice. *Performance Improvement Quarterly, 5*(2), 65–86.

Runco, M. A., & Chand, I. (1994). Problem finding, problem solving, and creativity. In M. Runco (Ed.), *Problem finding, problem solving, and creativity*. Norwood, NJ: Ablex Publishing.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 3.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In Barry Smith (Ed.), *Liberal education in a knowledge society*, 67–98. n.p.: Open Court.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Schön, D. A. (1987). *Educating the reflective practitioner*. San Francisco: Jossey-Bass.

Schrader, S., Riggs, W. M., & Smith, R. P. (1993). Choice over uncertainty and ambiguity in technical problem solving. *Journal of Engineering and Technology Management, 10*(1), 73–99.

Scott, C. A. (1994). Project-based science: Reflections of a middle school teacher. *Elementary School Journal*, 75–94.

Strobel, J., & Van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing pbl to conventional classrooms. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 4.

Svihla, V. (2009). *How differences in interaction affect learning and development of design expertise in the context of bio-medical engineering design.* PhD dissertation, University of Texas, Austin.

Svihla, V., Reeve, R., Field, J., Lane, W., Collins, J., & Stiles, A. (2016). Framing, reframing and teaching: Design decisions before, during and within a project-based unit. *International Journal of Designs for Learning, 7*(1), 19–36.

Tracy, P. (2005). *Design and problem finding in high schools: A study of students and their teacher in one queensland school.* Master's thesis, Griffith University.

Verhaegen, P.-A., Peeters, J., Vandevenne, D., Dewulf, S., & Duflou, J. R. (2011). Effectiveness of the panda ideation tool. *Procedia Engineering, 9*(0), 63–76. doi: http://dx.doi.org/10.1016/j.proeng.2011.03.101

Vygotsky, L. S. (1978). *Mind in society: The development of higher mental processes.* Cambridge, MA: Harvard University Press.

Walker, A., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 6.

Woodhall, T. F. (2011). Designing a rubric to assess the problem definition phase of student design projects in upper year engineering courses. Master's thesis, Queen's University at Kingston Ontario Canada.

Wynn, D., & Clarkson, P. J. (2005). Models of designing. In P. J. Clarkson & C. Eckert (Eds.), *Design process improvement–A review of current practice* (pp. 34–59). London: Springer.

Zydney, J. M. (2008). Cognitive tools for scaffolding students defining an ill-structured problem. *Journal of Educational Computing Research, 38*(4), 353–385.

Vanessa Svihla is an assistant professor in organization, information & learning sciences at the University of New Mexico in Albuquerque. Dr. Svihla's research focuses on how people learn as they design. In particular, she studies problem framing processes across settings to understand ways ownership and identity intersect with learning. Dr. Svihla was the recipient of a 2014 National Academy/Spencer Foundation Postdoctoral Fellowship. She co-edited *Design as Scholarship: Case Studies from the Learning Sciences*, a volume that reports stories of researchers as designers.

Richard Reeve is an assistant professor of information and communication technology in teaching and learning at the Faculty of Education, Queen's University, in Kingston, Ontario. Dr. Reeve's research focuses on designerly activity by both teachers and students. In particular, his work examines the development of technology-supported knowledge-building communities, and how teachers collaboratively develop innovative approaches to teaching with technology. He explores how professional development contexts might provide support for these "designerly" endeavors. He co-edited *Design as Scholarship: Case Studies from the Learning Sciences*.