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Bridging Academic Disciplines with Interdisciplinary Project-based Learning: Challenges and Opportunities

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ABSTRACT

This article describes the implementation of an interdisciplinary design studio as a means to teach creative problem-solving through project-based learning. "Learning and Innovation Skills" has been designated as a core skill that students need to be successful in today's world, and project-based learning is one approach to helping students develop these skills. After describing the early genesis and development of the interdisciplinary design studio, the article describes results of initial research into the students' experiences in studio courses. Students described courses as flexible and reported high levels of motivation stemming from the authenticity of the problems. Because of the interdisciplinary nature of the studio, some students described deepening disciplinary skills while at the same time being exposed to cross-disciplinary skills. They believed the courses helped develop interdisciplinary collaboration, creativity, and communication skills.

Keywords: project-based learning, design studio, interdisciplinary creativity

The Partnership for 21st Century Learning has designated "Learning and Innovation Skills," including critical thinking and problem-solving, communication, collaboration, and creativity, as core skills students need to be successful in today's world ("Partnership for 21st century skills: Framework for 21st century learning," 2014). One strategy that can help improve how we teach and experience creative problem-solving is interdisciplinary collaboration. Because many employees are asked to solve problems themselves that are increasingly complex and interdisciplinary, this type of divide-crossing collaboration has become essential to problem-solving. As Katehi and Ross (2007) argued, dialogues across disciplines allow us to "address critical and socially relevant issues leading to far greater cultural impact" (p. 89). Indeed, English (2008) explained that "employees draw effectively on interdisciplinary knowledge in solving problems and communicating their findings" (p. 188), raising, in her mind, the question of how schools can best prepare students for this type of work environment.

One approach with the potential to foster creative problem-solving is project-based learning, the type of authentic problem-solving that is characteristic of design studios. Furthermore, interdisciplinary design studios may develop students' interdisciplinary collaboration and problem-solving skills by allowing them to collaborate on an authentic project that has personal meaning as well as authentic meaning outside of the school environment. However, this method is under-researched and under-utilized. What is needed are more examples of interdisciplinary collaboration through authentic, project-based learning in higher education. In this article, we describe the development and initial implementation of an interdisciplinary design studio to support project-based learning. In particular, we report on how students experienced courses and the thickly authentic learning environment and challenges of interdisciplinary collaboration. Rather than provide an in-depth description of a single interdisciplinary project-based learning course, we summarize student experiences across a range of courses held in the interdisciplinary design studio. We believe our research reflects the realities of implementing an interdisciplinary design space at a university, and our findings provide insight for others striving to teach interdisciplinary collaboration and design in higher education.

Literature Review

In this article, we describe the initial implementation of an interdisciplinary design studio in a university library. The studio space was created to support interdisciplinary project-based learning. Before describing the development of the studio, we review other literature on project-based learning, interdisciplinary collaboration and creativity, and design studio pedagogy.

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Project-based Learning

Both project-based learning and problem-based learning are open-ended, learner-centered approaches that emphasize students' independence and collaboration by centering on solving a problem (Brassler & Dettmers, 2017). However, while problem-based learning emphasizes knowledge gained while solving some problem, project-based learning focuses on the production of some artifact (Grant, 2011). Core features of project-based learning include an authentic project that drives learning (Brassler & Dettmers, 2017; Grant, 2011; Helle, Tynjälä, & Olkinuoura, 2006; Lee, Blackwell, Drake, & Moran, 2014), learner autonomy (Hell et al., 2006; Lee et al., 2014), active exploration of the problem by gathering needed resources (Lee et al., 2014), collaboration in teams (Grant, 2011; Lee et al., 2014), and embedded assessment practices, including assessment of the final project (Lee et al., 2014). Lee et al. also suggested community partnerships, where students collaborate with professionals, as an important component of project-based learning. In this article, we discuss a certain type of project-based learning—interdisciplinary project-based learning in a design studio—as a method for developing interdisciplinary, creative problem-solving skills.

Creativity, Design, and Interdisciplinary Collaboration

The type of project-based learning described here utilizes interdisciplinary design, which both requires and inspires creativity. Here, we use Stein's (1953) standard definition of creativity: "The creative work is a novel work that is accepted as tenable or useful or satisfying by a group in some point in time" (p. 311). In other words, creativity is creating something that is both an original idea and effectively fulfills some purpose. Design, on the other hand, describes "the conception and realization of new things," (Cross, 2006, p. 1), a quality of which can be creativity. The "new things" are not just physical objects, but can also include activities, services, process, systems, environments, and values, thus addressing social, cultural, and systemic problems (see Buchanan, 1998). Design methods are particularly useful for addressing complex, "wicked" problems (Rittel & Webber, 1973). Wicked problems are intransient, ill-defined, and often systemic problems that resist solution (Jordan, Kelinsasser, & Roe, 2014). Designers' patterns of reframing problems while searching for solutions make design an effective tool for addressing wicked problems (Dorst, 2015).

The complexity of the types of problems often addressed in design demands an interdisciplinary approach. Lattuca (2002) described interdisciplinary learning is when everyone works "on a common problem with continuous intercommunication among the participants from the different disciplines" (p. 712). Interdisciplinary work can increase creative and original thinking, providing new ways to solve problems (Wilson & Blackwell, 2013). Collaborators must learn to integrate the vocabulary, perspectives, and core values from other disciplines into their own work, helping them view problems from different perspectives and making the way for new approaches to solving them (Kellam & Cramond, 2010; Wilson & Blackwell, 2013). Interdisciplinary thinking can enable participants to find novel solutions to complex problems in future work (Wilson & Blackwell, 2013).

Although valuable, interdisciplinary work can be challenging. Challenges include managing teams of diverse students and faculty, balancing the depth and breadth of student learning, and navigating university structures. First, Brassler and Dettmers (2017) highlighted the high potential for conflict among interdisciplinary groups. Teams can struggle to communicate across disciplinary boundaries, find common goals, set appropriate expectations, and estimate time and effort for project completion. This can lead to a high rate of failure in interdisciplinary programs (Lee, 2014). Thus, participants (students and faculty members) need support to effectively engage in interdisciplinary problem-solving (Brassler & Dettmers, 2017; Epstein, 2005; Spelt, Biemans, Tobi, Luning, & Mulder, 2009). Second, degree programs must carefully evaluate the tradeoffs between disciplinary depth and interdisciplinary breadth. Davies and Devlin (2010) emphasized the need for students to develop deep disciplinary knowledge, including disciplinary vocabulary and cognitive maps, and cautioned interdisciplinary work can detract from these goals. Finally, university structures can hinder interdisciplinary work for both faculty and students. Barriers include difficulty assessing student learning (Lyall, Meagher, Bandola, & Kettle, 2015), evaluating teaching and scholarship (Davies & Devlin, 2010), coordinating logistics, including scheduling and allocating resources (Davies & Devlin, 2010; Kezar, 2005; Lyall et al., 2015; McCoy & Gardener, 2012), and assigning appropriate credit for faculty who participate in interdisciplinary teaching and research (Davies & Devlin, 2010; Kezar, 2005; Lyall et al., 2015; McCoy & Gardener, 2012).

It is critical that we explore new and innovative ways to teach collaborative, interdisciplinary problem-solving skills to students. An exciting example is the proposal from Connor, Sosa, Jackson, and Marks (2017) that described a new degree with problem-solving skills at the center of a nexus of three disciplines so that learning becomes a "journey through different models of disciplinary collaboration" (p. 212). In the absence of an entire degree focused on interdisciplinary, creative problem-solving, an alternative could be the development of interdisciplinary problem-solving experiences, such as could be attained within a design studio approach to teaching. In particular, an interdisciplinary

design studio creates a dedicated space for authentic, interdisciplinary, project-based learning. Next, we describe the historical and pedagogical background of the design studio.

Design Studio

The design studio tradition can be considered a type of authentic, project-based learning. Design studio pedagogy stems from the Ecole des Beaux-Arts in France (Cennamo, 2016; Shaffer, 2003). There began the tradition of students working on open-ended projects with support provided by discussions amongst pupils and instructors during public work presentations. Design-theorist Schön described studio pedagogy as an example of Vygotsky's (1978) zone of proximal development, where learners develop facility at the edge of their ability with the support of an instructor or more advanced peer.

In studio-based pedagogy, learning takes place in the social context of the studio. Students learn by working on authentic problems with other students and professionals from the community. Cennamo and Brandt (2012) described a studio as a class, a space, and a pedagogical method. Common characteristics of the studio class include small class sizes, a student-centered approach (Brandt et al., 2011; Broadfoot & Bennett, 2003; Brocato, 2009), an extended block of class time (Brocato, 2009; Cennamo, 2016; Cennamo & Brandt, 2012; Shaffer, 2003), and faculty to serve as a liaison between students and the professional community (Brandt et al., 2011; Shaffer 2003).

Like other forms of project-based learning, the central hub of studio pedagogy is a real, ill-structured project, usually with a concrete deliverable. Students work on the project as individuals or in small groups. Brandt et al. (2011) and Brocato (2009) highlighted an iterative process to project work. Brocato described the process as "propose-critique-iterate" (p. 141). Students share their project work, either through informal sessions where students present their work for self-, peer-, or instructor-critique, or through formal presentations that can include members of the professional community. Students then use personal reflection and feedback from others to refine their work.

Studio pedagogy has been applied to a variety of disciplinary and interdisciplinary academic settings. Brandt et al. (2011) studied design studios in industrial design and human-computer interaction. Other scholars have studied studio courses in information management (Carbone & Sheard, 2002), teacher education (Brocato, 2009), instructional design (Clinton & Rieber, 2010), physics (Wilson, 1994), and creative writing (Tassoni & Lewiecki-Wilson, 2005). Recognizing the need for students to develop interdisciplinary design skills, some have established interdisciplinary design courses or programs that incorporate design studio pedagogy (Bronet, Eglash, Gabrille, Hess, & Kagan, 2003; Costantino, Kellam, Cramond, & Crowder, 2010; Self & Back, 2017; Sochacka, Guyotte, Walther, Kellam, & Constantino, 2013).

Problem-based learning, project-based learning, interdisciplinary collaboration, and design studios can all be examples of what Shaffer and Resnick (1999) called "thickly authentic" learning experiences (p. 28). They described four types of authentic learning: learning that is personally meaningful, that is closely related to the real-world outside of school, that allows opportunity to apply disciplinary modes of thinking, and that uses assessment methods that reflect the learning process. Shaffer and Resnick suggested thick authenticity occurs when all four kinds of authentic learning occur together. They described, "'Thick authenticity' refers to activities that are personally meaningful, connected to important and interesting aspects of the world beyond the classroom, grounded in a systematic approach to thinking about problems and issues, and which provide for evaluation that is meaningfully related to the topics and methods being studied" (p. 195).

In this article we describe the development of an interdisciplinary design studio created to support project-based learning in our university library. Although the space was designed to support a design studio approach, the implementation of studio pedagogy differed across courses. However, what all courses had in common was interdisciplinary, thickly authentic, project-based learning. It is this type of learning we propose might help students develop interdisciplinary problem-solving skills that enable them to better address complex, wicked problems.

The variety of approaches implemented in the design studio reflects the authenticity of our research: it is unlikely that any two interdisciplinary studio courses would be implemented the same way. Indeed, Lee et al. (2014) found that even faculty members who participated in the same project-based learning professional development workshops interpreted and implemented project-based learning differently. However, we found in our research some common themes concerning how students experienced interdisciplinary design studio courses. In this article, we start by describing the development of the studio space and some of the courses held there.

Studio Development and Context

In 2012, a group of university faculty members at a private university formed a Creativity, Innovation, and Design (CID) group. Membership included faculty from across the university, and members met monthly to share ideas, discuss research partnerships, and promote creativity, innovation, and design on campus.

In the winter of 2014, several CID faculty members received permission to try teaching interdisciplinary courses on creativity, innovation, and design in the university library. The core development team included a librarian; faculty from the business, fine arts, and education school; and a consultant for the university's teaching and learning center (see West, 2016). The space was to serve as a prototype for the kind of interdisciplinary collaboration that could exist if space and opportunity were provided. Surplus furniture was found and the space was quickly created by removing rows of books and inserting temporary walls. Nearby group study rooms were converted into spaces for smaller teams to work together (see Smart, Darowki, & Armstrong, 2019; Zaugg & Warr, 2018). Two courses were immediately moved into the space; an additional two courses were taught in the studio in the summer, five courses in the fall, and six classes the following winter. Table 1 outlines the courses taught in the space included in this study, including a breakdown by student discipline area.

A wide range of courses have been taught in the CID studio. Some classes met regularly in the space, while others utilized the studio for a few class periods. The studio was open to all students outside of regular class time. Additionally, a few projects, which we describe below, spanned multiple semesters, including Fundacion Paraguaya, DUST, and social innovation design. These projects provide an example of the type of problems students addressed in the interdisciplinary design studio.

Fundación Paraguaya (Winter Year 1–Winter Year 2)

In this course, professors from the communications and business schools challenged students to design a product that would generate social change. Students collaborated with Martin Burt, founder of Fundación Paraguaya, to promote Burt's Poverty Stoplight program. The program creates statistical and visual representations of poverty in Paraguay ("Fundación Paraguaya: Poverty stoplight," 2014). The data are used to identify how to best help families and can be shared with other non-profit organizations. Students worked together to create a commercial and documentary for the organization. A small group of students also traveled to Paraguay to meet with Burt, conduct interviews, and collect film footage.

DUST (Spring Year 1–Winter Year 2)

Students and faculty from the colleges of education, art and communications, information technology, and others collaborated with the University of Maryland, NASA, and the Computer History Museum to develop and promote an augmented reality game (ARG) focused on teaching science principles to teenagers. This project was funded by the National Science Foundation. Guidance was provided by faculty from the College of Fine Arts and Communication and the College of Engineering and Technology. The game was launched in Winter, 2015 (http://dustgame.byu.edu/). As an extension on this project, in Winter 2015 faculty members from the College of Engineering and Technology collaborated with an English professor to develop a similar game for a technical writing course.

Social Innovation Design (Fall Year 1–Winter Year 2)

Faculty from the business school assisted students in developing their own social innovation projects. Students from across the university brought their own ideas to the class, discussed their ideas with faculty and other students, and designed their projects. Projects included an internship program for at-risk high school students and a service organization run by professional athletes.

The interdisciplinary CID studio began as an experiment, and in essence a microcosm of design thinking pedagogy itself by cycling through multiple cycles of experimentation and improvement. The instructors who taught in this space came from many different departments on campus, fitting with the interdisciplinary nature of the space, and thus had varied backgrounds in design and problem-solving pedagogy. A commonality in their training was in using design thinking, in similar ways to the method founded by the d.School, to promote creative solutions to "wicked" problems. Most had academic training in a design or entrepreneurial discipline, and several had worked in industry applying these skills.

The monthly CID faculty meetings described above served as continual professional development for these faculty in the strategies of creative problem-solving. At these meetings, the faculty discussed their challenges in teaching and research, shared successes and classroom strategies, and discussed methods for improving the instruction of creative problem-solving in the studio as well as in other classes. In particular, faculty who were new to creative problem-solving pedagogies were mentored and taught by more senior teachers. Sometimes these instructors were invited to participate in the same Innovation Boot Camp (1 credit) that was available to students to learn design thinking strategies. Faculty also visited and learned from other programs, including the Stanford d.School and a regional school with a design thinking focus. In these ways, the CID faculty group provided faculty professional development in the method espoused by Irby (1996), by first developing an awareness of the importance of creative problem-solving, then developing general skills, and then through mentoring to develop more advanced skills.

Table 1. Studio courses and participants

Course	Business	FHSS*	Education	Engineering	Fine Arts and Comm.	Humanities	Life Sciences	Physical and Math. Science	Undeclared	Unknown	Total
Winter Year 1**										41	41
A: Children's Storybooks										25	25
B: Paraguay										16	16
Spring Year 1										54	54
C: DUST										40	40
Innovation Bootcamp										14	14
Fall Year 1	8		8	3	4	2	8		2	8	43
D: FnArt 301	2			2	4					2	10
E: PDBio 550R						1	4				5
F: BusM 490R	6					1	3				10
G: IPT 664			8							6	14
H: IPT 515R				1			1		2		4
Winter Year 2	1	16	2	5	32	1	0		1		58
FnArt301RMW					9				1		10
FnArt301TTh	1	2		1	21						25
RecM 497R		13									13
BusM 497R		1	2	1	2						6
IT492R				3		1					4
BusM490R											0
TOTALS	9	16	10	8	36	3	8	0	3	103	196

*Family, Home and Social Sciences

**The disciplines of students who participated in Winter Year 1 were not recorded; however, we provide here the total number of students who participated in the courses.

Method

From 2014 to 2016, we researched students' experiences in the studio, including how the pedagogical approach differed from other university courses and the resulting challenges and opportunities. We sought to answer the following questions:

1. How did students describe their experiences in the interdisciplinary design studio courses?
2. What did students describe as the primary challenges and opportunities of the interdisciplinary design studio?

We used a postpositivist qualitative approach to answer our research questions. Hatch (2002) explained that postpositivist researchers "are interested in capturing participant perspectives but in rigorously disciplined ways" (p. 15). Postpositivist researchers search for patterns, and "when potential patterns are discovered, deductive processes are used to verify the strength of those patterns in the overall data set" (Hatch, 2002, p. 15). Our research design focused on learning about student experiences through interviews, observations, and surveys. Sample sizes varied by semester; see Table 2 for more detailed information. We searched the data for salient patterns across participants that addressed our research questions.

Interviews

Interviews were conducted individually and in focus groups. During the first semester of the project, instructors recommended students for interviews in two of the courses. In subsequent semesters, all students were invited to participate in interviews. Student interview questions focused on the structure of the course, what students learned in the course, students' experiences in the course, and use of the library space and resources (see Appendix A for interview protocols). Interviews were also conducted with 12 faculty members and here are used to support the descriptions provided by the students. The first author transcribed the interviews, and the transcriptions served as the primary data source for this study.

Observations

The first author observed at least one session, and often several sessions, of each course held in the studio. Observations focused on pedagogical methods used by faculty (including the sequence of activities) and interactions among students and faculty. The first author recorded notes concerning pedagogical events (such as problems presented to students and the relationships among students and instructors) and interactions of student teams (See Appendix B for

Table 2. Student research participants by discipline

	Interview			Survey			
Major	Group	Individual	Video	Pre	Mid1	Mid2	Post
Business	7			11	9	7	9
FHSS*	0	1		1			0
Education	3	1		6	9	5	5
Engineering	7			10	4	2	14
Fine Arts and Comm.	15		2	2	4	5	26
Humanities	5			1	1	2	6
Life Sciences	3	1		1	8	5	6
Physical and Math. Science				4	1	1	2
Undeclared	1					1	
Faculty		1	1				
TOTAL	41	4	3	36	36	28	68

*Family, Home and Social Sciences

observation form). Observation notes primarily served to triangulate findings identified through analysis of the interview transcripts.

Surveys

We invited all students who participated in the initial courses to participate in online surveys. Each semester we conducted a post-course survey (Winter and Spring Semester Year 1: n = 37, Fall Year 1: n = 32). We also administered a pre-course survey in Fall Year 1 (n = 39), and Winter Year 2 (n = 50). Additionally, we asked students to complete two midterm surveys in Fall Year 1 (n = 36 and n = 32). In addition to free response questions, the surveys included Likert scale questions on which students were asked to rate statements about the course experience (see Appendix C for free response survey items and Appendix D for full Likert scale item results). The items were based on two existing instruments: the Epstein Creativity Competencies Inventory (Epstein, Schmidt, & Warfel, 2008) and the Runco Ideational Behavior Scale (Runco, Plucker, & Lim, 2001). Additional items were added to evaluate course outcomes. Although the survey did not undergo rigorous testing, the responses provide useful information to triangulate findings established through analysis of the interview transcripts and observation notes.

Data Analysis

In our research, we followed an analysis process that Hatch (2002) labeled "typological analysis" (p. 152). As Hatch described, "Data analysis starts by dividing the overall data set into categories or groups based on predetermined typologies" (p. 152). He explained that these typologies can be derived from theory, common sense, or research objectives. The first author completed the coding and analysis, with the second author reviewing the results. The first author started the analysis by creating a set of codes that reflected the research questions. These codes included broad categories such as "how learning is different," "what students learned," "collaboration," "university aims," and "library use." As she coded the data, she added additional sub-codes based on patterns emerging from the data. For example, students described learning about knowledge and skills related to their own discipline as well as skills and knowledge from other fields. She also observed that students frequently described learning attitudes and values not related to any specific discipline. Thus, she broke the category "What students learned" into three sections: "Learned in field," "Learned out of field," and "Attitudes and thinking skills." This division enabled her to identify patterns of what students learned. She first coded passages in interview transcripts, then applied the refined coding scheme to the observation notes and open-ended survey responses.

After the initial coding was complete, the first author read the data for each code. She recorded patterns, themes, and impressions in memos and wrote summaries of each memo. She looked for evidence for and against emerging themes, including verifying identified themes with the Likert scaled survey items. The second author critically examined the coding, memos, and themes and provided suggestions for revisions.

Survey results were averaged across all program participants. Here, we report average Likert-scaled responses for several survey items. Student responses range from 1 ("strongly disagree") to 5 ("strongly agree"). See Appendix D for full survey results.

Trustworthiness

Trustworthiness was established through prolonged engagement in the research setting, multiple types of triangulation, and an audit trail. First, the study covered a significant period of time (four semesters or 1 1/2 years), and the authors were continuously engaged with the context across this time. The first author conducted interviews and observations across the second, third, and fourth semester. The second author worked as part of the CID faculty group that developed the studio and conducted the interviews during the first semester. Second, the study used several types of triangulation (see Guba, 1981). Triangulation occurred across participants in multiple courses, through multiple data sources (interviews, observations, and surveys), and through comparison of results with findings and theories from other studies. Finally, the first author kept a detailed audit trail and research journal throughout the research study. Both were reviewed by the second author.

Findings

Students described the studio courses taught in the CID studio as different from other courses they had taken. The courses were flexible: students designed their own learning experience and independently managed their work. Students were motivated by the nature of the problem to be solved, not by course grades. Instructors were mentors and consultants, and students accessed information through university libraries, university specialists, guest speakers, and collaborating organizations. In addition, students were working with students and faculty from disciplines different from their own, opening up unique challenges and opportunities. In this section, we will first present themes concerning how students described their interdisciplinary design studio experiences. Then we will discuss opportunities and challenges students identified.

The Interdisciplinary Design Studio Experience

The students felt that they learned more in this type of setting than in a traditional course. One student explained, "You're not just taking a class, you're having an experience." In fact, when asked about the class, many students described their "experience," not "the course" or "the class." Several elements made studio courses especially effective for students, including the support and mentorship of the instructors, the open-ended nature of the learning environment, and high levels of authentic motivation.

Faculty mentorship

As mentioned in the introduction, faculty members had varying experience with this type of pedagogical context. While some of the instructors were experienced in project-based learning contexts, others were just beginning to teach in this way. Faculty members highlighted a tension they had to navigate: they needed to support students through a new type of learning context while at the same time letting students explore on their own, sometimes even letting them fail. One faculty member told us, "I've had to be more willing to let students learn for themselves, to let them fail at times. I have to work against always jumping in to provide the right answer." Another faculty member commented on the importance of beginning with a flexible course structure that could be adapted as needed and the need to proactively seek learner feedback throughout the course.

Three primary roles of faculty members were apparent in the data. First, faculty guided students through the process of design, including leading them in brainstorming sessions, prototyping, and testing. Second, faculty members mentored students on their projects. Many class sessions consisted of students working on projects in small groups, and we observed faculty meeting with each group and sometimes with individual students. Evidence of this theme was clear on end-of-course surveys where students rated the statement "I felt the instructor was a mentor and a consultant more than a typical teacher" an average of 4.17 (SD = 0.92). Third, faculty pushed students to think critically about their ideas and better consider user needs. This happened in various settings, including individual or small-group mentoring sessions as well as whole-class discussion. Finally, faculty supported students in navigating complicated contexts and obtaining needed resources. For example, when a project was negatively affected by decisions government officials made without the students' knowledge, the course instructors shared in the frustration with the students and helped them find a new way forward.

Open-ended learning

The experiential nature of studio courses stemmed from the open-ended nature of the learning environment. Students felt the type of learning in these courses was more "realistic" and flexible compared to traditional college courses. While in a traditional course teachers instruct students in the subject area and assign specific assignments, in these courses teachers did not give students specific assignments with specific grading criteria. They guided them through the innovation process. An illustration student explained:

> I am used to a class that is very structured. I do an initial part of the drawing, I show my professor, and get feedback from him, and then I go back, make changes, and keep reworking it until the finished product . . . For the first time, I am on my own, I have to figure out those problems by myself and figure out a solution. So I feel like I grew up a lot as an artist.

Customizing the learning experience

Because of the open nature of the courses, students were able to customize their learning experience. An engineering student described:

> You get to decide what your learning experience is like . . . and place more emphasis on what you want to work on and what areas you're weak in, then find those people in the class that have different skill sets that can help push you in those areas . . . It's more like customizing the learning experience exactly to how you want.

Another student described how this customization added to the value of the course: "The freedom that you are given as a student in the class to make it your own and decide what you want to work on makes the class particularly valuable."

Although the instructors structured the courses around a central problem, such as producing children's storybooks or innovations for social change, in most courses students chose the specific projects to work on, the students they worked with, and their role on the team. One student reported, "I wasn't 'forced' into a particular learning role; rather, I could choose what I wanted to contribute based on my individual talents." These feelings were widespread—survey participants rated the statement "I was able to choose the kind of role I played on the team and the kind of work I completed on the project" an average of 4.18 (SD = 0.96)

Managing work and deadlines

In addition to setting individual goals and choosing team roles, students took responsibility for managing the work itself. One student commented, "I've learned how to ask for

and define the next step in our project instead of having it all set up for me." Students worked with their team to identify what tasks needed to be done and when they needed to be completed.

The open structure and freedom to choose tasks and deadlines meant students were often stepping into the unknown. As one student described, "Everything is new; everything is trailblazing." An engineering student added:

> Sometimes it's just not possible with this thing because we're doing things that haven't been done before, necessarily. Whereas, I think a lot of classes . . . it's just a project that the teacher already has done, you know it works, you know you can do them, and here it's more of a "maybe."

Students experimented with new ideas because they felt their instructors trusted them. A student who worked on the ARG project described, "Trust and autonomy on all levels allowed us the freedom to play around with ideas and pursue avenues we might otherwise have been afraid to follow." The open structure of the course gave students room to explore the unknown, and the trust of the instructors gave students the confidence to do so.

Students said that managing time in this setting was different from managing time for traditional school assignments. One student reported, "There is a vast difference between homework assignment time tables and commercial time tables. I surprised myself at how quickly I could get things done when I was under the gun." A fine arts student similarly explained, "Most classes focus on schedules and tests and books to teach various principles. However, this class allows students to feel what it's like to have to make deadlines or else the client loses trust in the organization."

Authentic motivation

Many students were motivated to do their best work for these courses. An illustration student recounted, "I like the work I am doing in this class the most of any class I am taking . . . I feel like people are doing really good work, like pushing themselves to do really good work." Students took initiative to do extra work, including working on projects after the semester was over. Students also wanted to expand the size of the projects and expressed the desire to involve more students. Finally, students wanted to share their project with the community and the world. A student who worked on the Fundación Paraguaya project explained, "Once we had been thinking about it, and we kind of realized what this could be, and we were just like, how does this not already exist? The whole world needs to know about what this is and what it can do." One of her teammates echoed, "The world needs to see this."

High motivation appeared to come from factors in addition to grades. When we asked students to rate their personal motivation to do well beyond a grade on the project, their responses averaged 4.15 (SD = 1.00). Furthermore, students rated the statement "I felt responsibility for my portion of this project and for making it as good as possible" 4.45 (SD = 0.81). Students said that this motivation stemmed from the following factors: (a) projects that had a significant impact on the world, (b) completing authentic work relevant to their future careers, (c) student autonomy, and (d) collaboration with outside specialists and organizations.

Interdisciplinary Collaboration: Challenges and Opportunities

Because of the interdisciplinary nature of these courses, students developed problem-solving skills beyond what they would normally build in a disciplinary studio course. By working with students from other fields, students expanded interpersonal skills, deepened disciplinary knowledge, and expanded understandings of other disciplines. By the end of the courses, students indicated feeling that they were better prepared to enter the workforce.

Teamwork and interpersonal skills

Many of the things students learned were soft skills critical to success in careers, such as communicating effectively, working with others, and leading and managing a team. Students worked with different kinds of people: people from different disciplines and with different work habits, communication styles, and personalities. One student explained that the class "forces us to be with people that are not like us." He said students learned "how to work together . . . and to have things work and not work and dealing with different people." Other students agreed. One commented, "I learned how to collaborate with people that I really didn't like. That was hard to do but was, in my opinion, successful." Many students echoed this theme: working with different people, sometimes people they didn't like, was difficult, but it was a valuable experience.

Learning from other students

Students said they normally worked with students from their own discipline who used the same vocabulary and shared similar perspectives. Students said the interdisciplinary collaboration provided new perspectives on both their own discipline and other fields. An advertising student described, "In advertising . . . we have all been taught the same things, so we have the same vocabulary, and even though we have different perspectives, it's still an advertising perspective." Other students described their experiences in their disciplines as being "stuck in a rut," feeling "siloed," and even

becoming "snobby." However, students commented that the CID courses "opened [their] eyes," were "exciting," provided "fresh perspectives," and enabled "new opportunities."

Students explained that working with others with different views led to better ideas and products. An engineering student explained, "To have all these different minds come together . . . you get better ideas, you get fresh ideas, and you just get different perspectives about everything." Another student commented, "I enjoyed working [with other students] because most of us came from different majors, so we brought a variety of ideas and perspectives to the table."

In addition to leading to potentially better ideas and products, students believed the interdisciplinary collaboration helped them grow within their own disciplines. Students learned techniques from other fields that they applied to their own work. For example, Emily, an English teaching major, and John, an illustration student, worked together in the children's storybook class. Emily described her work with John:

> It was so neat to have to challenge ideas, to really flesh out the characters because John is sitting here, "How does that work?" So we were able to create a more in-depth story and universe . . . I would like to do that when I write more.

Emily found John's methods of questioning her characters led to deeper character development and a better story. John saw the characters through the eyes of an illustrator, and Emily's writing profited from his perspective. John described similar benefits from his collaboration with Emily. He commented that the collaboration "really stretched me as an artist to think about things in a different way." These students' experiences demonstrated how working with students in other fields lead to professional growth.

Collaboration challenges

Not all students had the same collaborative experience John and Emily described. Scott, an editor participating in the same interview as John and Emily, explained:

> When John and Emily talked about how good of a collaboration there was, I am like, where is mine? Like I feel some of us had good collaboration, especially as illustrator to author, but . . . as an editor, I was kind of the spell checker, and not so much the helper.

Further group discussion revealed that this problem might have developed because students didn't know how to use an editor. Although John and Emily described having a good collaborative session with student editors early in the course, they did not utilize editors at all during the rest of the semester. They said they didn't know what role an editor was supposed to play. Scott mentioned that he could have been more proactive in offering support to other students. Several students expressed feelings similar to John's, Emily's, and Scott's; some felt they didn't have the background knowledge or structure needed for successful collaboration, while others described the benefits of applying their disciplinary knowledge to their projects.

Uneven workloads was another interdisciplinary challenge that students faced. The editing students in the storybook class described completing their part of the projects in the first few weeks of class and then had less work load. An editing student described, "I feel like . . . it has been a little uneven, workwise, because we all have different roles, but those roles don't necessarily play the same amount of time and work, especially in a project like this." The illustrators described having too much to do in a four-month course. A programming student who worked on the ARG project also expressed concerns about work division. He said the first two to three weeks of the seven-week course were spent researching science and "figuring out what the app's supposed to be." The programming students were not able to begin programming until a few weeks into the course, creating too little work at the beginning of the term and too much at the end.

Another challenge that the collaborative environment presented was ensuring quality and providing students with discipline-specific feedback. The students in the courses came from different points in their degree programs and had different amounts of experience. A few older students were frustrated at the low quality of work from some of their teammates. Working with students from other fields compounded this; students did not know how to help teammates from other disciplines. A senior majoring in illustration explained, "It would be nice to have more critiques with people in your field so that you could get opinions from other people who know exactly what they are talking about." Another student described not knowing how to give feedback to her classmates:

> One of the challenges as a writer is I am not used to working with illustrators that closely. When they ask for my feedback, I don't want to step on your creative liberty. I want you to be able to take this and make the vision you want with it. Finding that balance between letting them do that and actually giving good feedback was something.

Students navigated these challenges by consulting university faculty and specialists in their own field.

Communication

Students learned that successfully working with different people required effective communication skills, including careful listening and the ability to explain difficult concepts to others. An advertising student described learning to listen. He said that his communication style was short and to the point, and he got frustrated with students who talked for lengthy periods. He explained, "I always tried to take everyone's opinion, but get the gist of what they are saying, put it together, and . . . make a decision and move forward." However, he noticed that other students communicated differently: "A lot of the more creative minds really have to express a lot to come to their final conclusion. I felt like it was beating around the bush. They felt like it was an expression of their inner passion and desire." He explained how his feelings changed over the course of the semester:

> It was very hard in the beginning of the semester to listen to everyone's ideas . . . In the end, though, their vision was so clear, and they were just trying to explain their whole vision . . . that has made the project a lot better because their vision was so great. I think that me, as a more count person, I have to learn how to . . . be patient, and listen to the whole process, because the end result was really quite beautiful.

In addition, students found that disparate vocabularies made communication with peers from other disciplines difficult. An advertising student explained, "Coming in and working with everyone, sometimes it took us a while to get over the different viewpoints and vocabulary . . . we were just talking in circles . . . Once we figured it out, it was like we all wanted the same thing the whole time." Students also needed to learn how to explain their work to those of other disciplines. A student who worked on the ARG project told us, "I've learned how to explain technical, or things that I'm more an expert at, in a way that other people can understand." Several engineering students who worked on the ARG project described struggling to explain what technology "can and cannot do" to those from other fields. For example, students were working on a "chatbot," a computer application designed to have a conversation with users. The programming students collaborated with writing students who would write the script for the program, and the engineering students had to explain the technical limitations of the programs to the writers. Many students felt that the ability to explain disciplinary-specific concepts to others was vital to working well with those of other disciplines and good preparation for their careers.

Disciplinary knowledge

Through these courses, some students gained knowledge and developed skills related to their major programs. Like Paula, the advertising management student described above, many students were able to practice skills they learned in core classes, resulting in a deeper understanding of their disciplines. A student majoring in English and minoring in editing described:

> I feel like as an editor I learned things that I wouldn't have learned in my [editing class]. I learned how to work with an author and see what she wants for her book and be able to help her capture her vision . . . You really get hands-on experience like you would get in an internship.

Others had similar experiences. Several programming students said they learned how to apply new programming languages to different settings. An art student learned to be mindful of his audience: "I learned that a visual style for an expansive project like this one needs to be clearly decided with the audience in mind." A student majoring in music composition also described becoming more aware of his audience: "I learned . . . more about the audiences my music targets." These skills will assist students in their careers.

Learning about other disciplines

The interdisciplinary nature of CID courses also exposed students to skills outside of their disciplines, as evidenced by survey responses. Students rated the statement "I learned new things unrelated to my previous areas of expertise" an average of 4.44. In particular, students gained specific skills they needed to work effectively on projects with those from other disciplines. For example, an advertising student learned about computer programming when she became a writer for a character in a computer program. She described, "I am lead writer for the AI [Artificial Intelligence] character, so in order to write her dialogue I had to learn a little bit of how to make that work in the code, rather than just write it like a script." As we described above, the engineering students taught her the principles of programming she needed to write the script. Other students described learning more about science education and marketing, as well as developing new skills such as using Photoshop and WordPress software.

Students also described learning through casual interactions with their peers. Several students said they enjoyed watching "how artists create work," or "what goes into illustration." They learned about the video making process and advertising briefs. Several students said they discovered new hobbies from their interactions with their peers.

Preparing for the future

The students we interviewed recognized the future value of the skills they developed in CID courses, including an advertising student who commented, "I think this atmosphere and learning space has been the most useful thing for me so far." Many students believed that this usefulness was grounded in the practical and problem-based nature of CID projects. An engineering student explained, "You are making a product that is more like what you're going to be doing in the career you're in."

Several students said that their experiences in the CID studio will help them transition into the workforce. While describing his internship experience in New York, Levi explained, "I think the learning curve that you kill by being in an activity like this is going to be amazing. I feel so much more prepared for . . . the rest of my life." Another advertising student also said her experience would "break the learning curve": "It is so useful, and it is so ahead as far as education goes . . . You are going to break the learning curve. You are going to be ahead and you are going to understand a lot more things than you would if you had just stuck your head in your bubble." These students believed participation in CID courses would give them a jump-start on their careers.

Students mentioned several skills that will help them "break the learning curve," including working with different kinds of people and working autonomously. An advertising student felt that her experience working with different people would help her:

> We are going to be graduating and actually be going into production with a lot of projects that we work on, really anywhere I go, especially if I plan on working at an agency or anything, I am going to be working with these people in the future.

Students also valued the skills they learned from other disciplines. One student explained that the courses were "a great way to learn about what other students study and how that applies to my future environment." A music student agreed. He said that learning about business and public relations would help him as a composer. Students believed that they would enter the workforce with more confidence because of their participation in CID projects.

Discussion

In this study, we sought to understand students' experiences in interdisciplinary design studio courses, including the challenges and opportunities stemming from project-based learning that was interdisciplinary. In the literature review, we suggested that the interdisciplinary, project-based learning supported by the studio is an example of what Shaffer and Resnick (1999) described as thick authenticity, an interaction of four types of authenticity. Our analysis here highlights the challenges of meeting all four types of authenticity simultaneously. However, despite this limitation, students still reported having a valuable and rich learning experience.

Thick Authenticity

In our analysis, we identified evidence of several types of authenticity as described by Shaffer and Resnick (1999). First, students described projects as personally meaningful: they wanted to do their best work, including extra work where necessary, because they cared about the work they were doing. They had the autonomy to set their own goals and work towards them. Strong evidence for this theme was present on end-of-course surveys, where students rated their deep, personal motivation an average of 4.15 (SD = 1.00), and feelings of personal responsibility for their work an average of 4.45 (SD = 0.81). Lee et al. (2014) similarly found meaningful work contributed to intrinsic motivation, resulting in students choosing to work extra days. The second type of authenticity described by Shaffer and Resnick is learning that relates to the real-world, including completing work that impacts the broader community. This is particularly evident in one student's comment that "the whole world needs to know [about their project] and what it can do."

The third type of authenticity Shaffer and Resnick (1999) described was learning that provided opportunities for students to think in the modes of their disciplines. Some students showed evidence of this type of authenticity. For example, one student reported that she felt "like an editor," including learning things she wouldn't have learned in her editing classes, things that took hands-on experience to understand. However, other students did not have the same experience. John described not knowing how to act as an editor and didn't experience as rich of a collaborative experience. We discuss more about disciplinary learning in the next section.

The fourth type of authenticity, assessments that reflect the learning process, showed less prevalence in students' statements. Very few students discussed assessment practices beyond the irrelevance of grades. Our interview questions did not directly address assessment practices, and instructors might provide more insight into how they knew students were learning. However, assessing project-based learning can be difficult and it is crucial to student's learning; in particular, instructors must assess both the final project and deeper content understanding (Lee et al., 2014). Future iterations might consider prompting instructors to reflect on embedding authentic assessment into their courses.

The interdisciplinary and project-based format strongly supported personally meaningful and relevant work, but attention to disciplinary structures and assessment were limited. Future project- and problem-based learning programs should look for creative ways to support disciplinary development and assessment in interdisciplinary programs. For example, students might be required to consult with a faculty member from their discipline throughout the project or to reflect on lessons learned from the group project for their own individual discipline. Such an approach would enable students to better connect with disciplinary knowledge and get feedback on their work; however, consultants would need guidance on the type of assistance that is appropriate within the pedagogic structure (see Irby, 1996).

Challenges of Interdisciplinary Project-Based Learning

The challenges described by students are similar to those identified in other studies of project-based learning and interdisciplinary collaboration. First, some students struggled collaborating with others because of lack of disciplinary support and feedback. Providing disciplinary support is important in pedagogic collaboration (Davies & Devlin, 2010; Helle et al., 2006; Lee et al., 2014; Spelt et al., 2011). An interesting example comes from Self and Baek's (2017) study of interdisciplinary team teaching. In their study, students rated single-instructor courses higher than courses with multiple instructors. The authors proposed a lack of disciplinary depth might have contributed to these results: team teachers were more reluctant to emphasize any single discipline, resulting in no disciplinary foundation. This suggests that disciplinary depth, even if that depth comes from outside a student's core discipline, impacts students' experiences in interdisciplinary courses.

Second, collaboration was difficult because in many projects, students had varying workloads and timelines. For example, in the ARG project, programming students were not able to begin their work until much of the app design was complete, leaving a significant amount of work for the end of the semester. Managing workloads is a common problem in interdisciplinary project-based learning (Helle et al., 2006). For example, Contantinto et al. (2010) reported engineering and art students played different roles in an interdisciplinary project, resulting in less design work for art students. Students felt this limited the collaboration opportunities. Other scholars observed students commonly underestimate the time and effort required to complete projects (Brassler & Dettmers, 2017; Epstein, 2005).

Finally, like in other interdisciplinary contexts, students struggled communicating across disciplines; each discipline used different vocabulary and communication styles. Epstein (2005) described a similar issue in interdisciplinary research of faculty members. She described constructing a common, third vocabulary with collaborators, even recording key terms and definitions on index cards. Students, in particular, need support as they come to understand disciplinary boundaries and perspectives (Lattuca, Knight, & Bergom, 2013).

Research Limitations

While we believe the findings presented in this paper are well supported by the data, there are still many limitations to this study that require caution in generalizing the findings. First, while the courses involved were interdisciplinary, the number of disciplines participating was still small and mostly design-focused. What is yet unknown is how effectively other disciplines that do not emphasize creative problem-solving and design as heavily could be integrated into these experiences. In addition, the interviews with students were largely done as focus groups, and thus limited by the potential for bias and groupthink. Finally, the findings in this paper are based on self-description and student perceptions, and thus may not be completely accurate. Future research is needed to better validate these findings with a more diverse sample and more in-depth research methods, including assessment of student learning, creativity, and interdisciplinary competencies via a variety of methods.

Conclusion: Lessons Learned for Future Implementation

Overall, students describe benefiting from courses held in the interdisciplinary design studio because of the thick authenticity of the interdisciplinary project-based learning. Future instantiations of this type of design studio should pay heed to meeting the four types of authenticity described by Shaffer and Resnick (1999). Particularly, instructors should carefully consider how assessment methods both reflect the learning process and are effective at evaluating deep student learning.

The challenges students described suggest additional support and scaffolding, particularly as it applies to supporting disciplinary thinking and learning, might allow for a more successful experience. Faculty who teach project-based, interdisciplinary courses should consider how to support students in developing and applying disciplinary knowledge and interdisciplinary collaboration skills (including managing time and expectations as well as building a common vocabulary.

All in all, the project-based courses in the CID studio moved learning beyond traditional courses and beyond intra-disciplinary studio pedagogy. They provided students instead with opportunities to experience first-hand

the advantages and challenges of interdisciplinary creativity. When much of education emphasizes closed-ended testing and knowledge retention, opportunities such as those provided through interdisciplinary creative problem-solving are crucial to teaching students that "many problems have multiple 'right' answers" (Grupas, 1990, p. 4) and that interdisciplinary collaboration is often key to more productive work in their careers.

References

Brandt, C. B., Cennamo, K., Douglas, S., Vernon, M., McGrath, M., & Reimer, Y. (2011). A theoretical framework for the studio as a learning environment. *International Journal of Technology and Design Education, 23*(2), 329–348. https://doi.org/10.1007/s10798-011-9181-5

Brassler, M., & Dettmers, J. (2017). How to enhance interdisciplinary competence—Interdisciplinary problem-based learning versus interdisciplinary project-based learning. *Interdisciplinary Journal of Problem-Based Learning, 11*(2), 12. https://doi.org/10.7771/1541-5015.1686

Broadfoot, O., & Bennett, R. (2003). *Design studios: Online? Comparing traditional face-to-face design studio education with modern internet-based design studios.* In Apple University Consortium Academic and Developers Conference Proceedings 2003 (pp. 9–21). Adelaide, Australia. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=E36FCCD1F9EB81E5B9D66D1014D59989?doi=10.1.1.124.3548&rep=rep1&type=pdf

Brocato, K. (2009). Studio based learning: Proposing, critiquing, iterating our way to person-centeredness for better classroom management. *Theory Into Practice, 48*(2), 138–146. https://doi.org/10.1080/00405840902776459

Bronet, F., Eglash, R., Gabriele, G., Hess, D., & Kagan, L. (2003). Product design and innovation: Evolution of an interdisciplinary design curriculum. *International Journal of Engineering Education, 19*(1), 183–191.

Buchanan, R. (1998). Branzi's dilemma: Design in contemporary culture. *Design Issues, 14*(1), 3–20. https://doi.org/10.2307/1511825

Carbone, A., & Sheard, J. (2002). Developing a model of student learning in a studio-based teaching environment. *Informing Science, 5*, 203–215.

Cennamo, K. (2016). What is studio. In E. Boling, R. A. Schwier, C. M. Gray, K. M. Smith, & K. Campbell (Eds.), *Studio teaching in higher education: Selected design cases* (pp. 248–259). New York, NY: Routledge.

Cennamo, K., & Brandt, C. (2012). The "right kind of telling": Knowledge building in the academic design studio. *Educational Technology Research and Development, 60*(5), 839–858. https://doi.org/10.1007/s11423-012-9254-5

Clinton, G., & Rieber, L. P. (2010). The Studio experience at the University of Georgia: an example of constructionist learning for adults. *Educational Technology Research and Development, 58*(6), 755–780. https://doi.org/10.1007/s11423-010-9165-2

Connor, A., Sosa, R., Jackson, A. G., & Marks, S. (2017). Problem solving at the edge of disciplines. In C. Zhou (Ed.), *Handbook of research on creative problem-solving skill development in higher education* (pp. 212–234). Hershey, PA: IGI Global. https://doi.org/10.4018/978-1-5225-0643-0.ch010

Cotantino, T., Kellam, N., Cramond, B., & Crowder, I. (2010). An interdisciplinary design studio: How can art and engineering collaborate to increase students' creativity? *Art Education, 63*(2), 49–53. https://doi.org/10.1080/00043125.2010.11519062

Cross, N. (2006). *Designerly ways of knowing.* London: Springer.

Davies, M., & Devlin, M. (2010). Interdisciplinary higher education. In *Interdisciplinary higher education: Perspectives and practicalities* (pp. 3–28). Bingley, England: Emerald Group Publishing Ltd. Retrieved from http://dro.deakin.edu.au/eserv/DU:30033737/devlin-interdisciplinaryhigher-post-2010.pdf

Dorst, K. (2015). *Frame innovation: Create new thinking by design.* Cambridge, MA: MIT Press.

English, L. D. (2008). Interdisciplinary problem solving: A focus on engineering experiences. In *Proceedings of the 31st Annual Conference of the Mathematics Education Research Group of Australasia* (Vol. 1, pp. 187–193). ERIC. Retrieved from https://files.eric.ed.gov/fulltext/ED503747.pdf#page=180

Epstein, R., Schmidt, S. M., & Warfel, R. (2008). Measuring and training creativity competencies: Validation of a new test. *Creativity Research Journal, 20*(1), 7–12. https://doi.org/10.1080/10400410701839876

Epstein, S. L. (2005). Making interdisciplinary collaboration work. In S. J. Derry, C. D. Schunn, & M. A. Gernsbacher (Eds.), *Interdisciplinary collaboration: An emerging cognitive science* (pp. 245–264). New York, NY: Psychology Press.

Fundación Paraguaya: Poverty stoplight. (2014). Retrieved August 17, 2017 from http://www.fundacionparaguaya.org.py/?page_id=490

Grant, M. M. (2011). Learning, beliefs, and products: Students' perspectives with project-based learning. *Interdisciplinary Journal of Problem-Based Learning, 5*(2), 6. https://doi.org/10.7771/1541-5015.1254

Grupas, A. (1990). *Creative problem solving.* In The Annual Meeting of the Missouri Association of Community and

Junior Colleges. Retrieved from https://files.eric.ed.gov/fulltext/ED343813.pdf

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology Journal, 29*(2), 75–91. https://doi.org/10.1007/BF02766777

Hatch, J. A. (2002). *Doing qualitative research in education settings.* Albany, New York: State University of New York.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education—theory, practice and rubber sling shots. *Higher Education, 51*(2), 287–314.

Irby, D. M. (1996). Models of faculty development for problem-based learning. *Advances in Health Sciences Education, 1*(1), 69-81.

Jordan, M. E., Kleinsasser, R. C., & Roe, M. F. (2014). Wicked problems: Inescapable wickedity. *Journal of Education for Social Work, 40*(4), 415–430.

Katehi, L., & Ross, M. (2007). Technology and culture: Exploring the creative instinct through cultural interpretations. *Journal of Engineering Education, 96*(2), 89–90. https://doi.org/10.1002/j.2168-9830.2007.tb00919.x

Kellam, N., & Cramond, B. (2010). An interdisciplinary design studio: How can art and engineering collaborate to increase students' creativity? *Art Education, 63*(2), 49–54.

Kezar, A. (2005). Redesigning for collaboration within higher education institutions: An exploration into the developmental process. *Research in Higher Education, 46*(7), 831–860. https://doi.org/10.1007/s11162-004-6227-5

Lattuca, L. R. (2002). Learning interdisciplinarity: Sociocultural perspectives on academic work. *The Journal of Higher Education, 73*(6), 711–739. https://doi.org/10.1353/jhe.2002.0054

Lattuca, L. R., Knight, D., & Bergom, I. (2013). Developing a measure of interdisciplinary competence. *International Journal of Engineering Education, 29*(3), 726–739.

Lee, J. (2014). The integrated design process from the facilitator's perspective. *International Journal of Art & Design Education, 33*(1), 141–156. https://doi.org/10.1111/j.1476-8070.2014.12000.x

Lee, J. S., Blackwell, S., Drake, J., & Moran, K. A. (2014). Taking a leap of faith: Redefining teaching and learning in higher education through project-based learning. *Interdisciplinary Journal of Problem-Based Learning, 8*(2), 2. https://doi.org/10.7771/1541-5015.1426

Lyall, C., Meagher, L., Bandola, J., & Kettle, A. (2015). *Interdisciplinary provision in higher education: Current and future challenges* (pp. 1–97). University of Edinburgh. Retrieved from https://www.heacademy.ac.uk/system/files/interdisciplinary_provision_in_he.pdf

McCoy, S. K., & Gardner, S. K. (2012). Interdisciplinary collaboration on campus: Five questions. *Change: The Magazine of Higher Learning, 46*(6) http://www.tandfonline.com/doi/full/10.1080/00091383.2012.728953

Partnership for 21st century skills: Framework for 21st century learning. (2014). Retrieved from http://www.p21.org/about-us/p21-framework

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

Runco, M. A., Plucker, J. A., & Lim, W. (2001). Development and psychometric integrity of a measure of ideational behavior. *Creativity Research Journal, 13*(3-4), 393–400. https://doi.org/10.1207/S15326934CRJ1334_16

Self, J. A., & Baek, J. S. (2017). Interdisciplinarity in design education: Understanding the undergraduate student experience. *International Journal of Technology and Design Education, 27*(3), 459–480. https://doi.org/10.1007/s10798-016-9355-2

Shaffer, D. W. (2003). *Portrait of the Oxford Design Studio: An ethnography of design pedagogy*. WCER Working Paper No. 2003-11. Retrieved from https://files.eric.ed.gov/fulltext/ED497579.pdf

Shaffer, D. W., & Resnick, M. (1999). "Thick" authenticity: New media and authentic learning. *Journal of Interactive Learning Research, 10*(2), 195–215.

Smart, E., Darowski, E. S., & Armstrong, M. (2019). Library integration with design thinking courses. In D. M. Mueller (Ed.), *Recasting the narrative: ACRL Conference proceedings* (pp. 356–368). Retrieved from http://www.ala.org/acrl/sites/ala.org.acrl/files/content/conferences/confsandpreconfs/2019/InspirationIdeationImplementation.pdf

Sochacka, N., Guyotte, K. W., Walther, J., Kellam, N. N., & Costantino, T. (2013). *Faculty reflections on a STEAM-inspired interdisciplinary studio course*. In American Society for Engineering Education Annual Conference and Exposition. Atlanta, GA.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review, 21*(4), 365. https://doi.org/10.1007/s10648-009-9113-z

Stein, M. I. (1953). Creativity and culture. *The Journal of Psychology, 36*(2), 311–322. https://doi.org/10.1080/00223980.1953.9712897

Tassoni, J. P., & Lewiecki-Wilson, C. (2005). Not just anywhere, anywhen: Mapping change through studio work. *Journal of Basic Writing*, 68–92. https://www.jstor.org/stable/43443811

Vygotsky S., L. (1978). Interaction between learning and development. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher psychological processes* (pp. 79–91). Cambridge, MA: President and Fellows of Harvard College. Retrieved

from https://www.ncbi.nlm.nih.gov/pubmed/4139900

West, R. E. (2016). Breaking down walls to creativity through interdisciplinary design. *Educational Technology, 56*(6), 47-52.

Wilson, J. M. (1994). The CUPLE physics studio. *Physics Teacher, 32*(9), 518–523. https://doi.org/10.1119/1.2344100

Wilson, L., & Blackwell, A. F. (2013). Interdisciplinarity and innovation. In E. G. Carayannis (Ed.), *Encyclopedia of creativity, invention, innovation and entrepreneurship* (pp. 1097–1105). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4614-3858-8_371

Zaugg, H., & Warr, M. C. (2018). Integrating a creativity, innovation, and design studio within an academic library. *Library Management, 39*(3/4), 172–187. https://doi.org/10.1108/LM-09-2017-0091

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Appendix A

Student Interview Protocol

Group Interview Questions

1. How was this class similar or different from other classes you've had at BYU?
2. In this project, you worked on a very diverse team, with people who have different perspectives or disciplines. What benefit or challenges did this collaboration provide?
3. What are your thoughts about having the class and project here in the library space? What worked well about the arrangement? What could be improved?
4. Who did you work with (librarians, other faculty) to complete your project? Please describe how you discovered them. How helpful was it?
5. What did you learn from the project that related specifically to your content area?
6. What did you learn from the project that was outside of your content area?
7. Did you learn anything that is not really related to school at all that you thought was important? What was it, and how did you learn it? (creative process? Project management? Teamwork?)
8. Would you take a class like this again, similar structure but different project? Why or why not?
9. Tell me the three most important things or events that were critical to this project?
10. (Probe) How did those events occur? Who was involved? what happened? how did you develop the ideas?

Questions for informal interviews during observations

1. What is currently happening in the design (creativity process)?
2. How do you feel about what is happening? (What is working well what is not?)
3. What surprises you about the creativity process thus far?
4. What resources are available to help you with your project?
5. What do you anticipate will happen next?

Appendix B

Observation Protocol

Date: Location: Instructor(s):

Time	Activity

People

Initials	Name	Description

Date: Location: Environment

General Notes

Appendix C

Open-Response Survey Questions

We administered the full survey four times: April 2014, June 2014, December 2014, and April 2015. Scaled questions were identical in all surveys, but open-response questions differed slightly. See Appendix E for scaled survey questions. Additionally, we administered a pre-course survey in September 2014 and January 2015.

April 2014 Non-Scaled Questions

- What is your major?
- What year are you in school?
- What is your gender?
- How useful was the experience overall for you as a student? Please explain and give specific examples.
- How does this type of experience compare with your other BYU learning experiences?
- What kinds of things did you learn?
- What are the strengths and weaknesses of this approach?
- How can we improve the usefulness of the space where the class was taught and of the experience itself?
- With WHOM did you engage with (students, faculty library personnel) to complete the project?
- What PLACES on/off campus did you use to work on the project?
- What kind of SERVICES were helpful in completing the project?
- What kind of TOOLS and SUPPLIES were helpful in completing the project?

June 2014 Non-Scaled Questions

- Which college and department are you from?
- What year are you in school?
- What is your gender?
- How useful was the experience in this class and/or participating in this project overall for you as a student? Please explain and give specific examples.
- How does this type of experience compare with your other BYU learning experiences?
- What are the strengths and weaknesses of this approach?
- How did the space and location for the class (in the library) contribute to or detract from the learning experience? Please give specific examples.
- How can we improve the usefulness of the space where the class was taught and of the experience itself?
- What did you learn, if anything, this semester, related to your content area? Please give specific examples.
- What did you learn, if anything, this semester not related to your content area? For example, consider other content areas, or even non-content learning, such as how to be more creative, collaborative, etc. Please give specific examples.
- Outside of your instructors, did you work with or learn from anyone else to help you in this class? For example, consider librarians, other faculty or students from your department, outside professionals, etc. If so, please list who they were and what they helped you with.
- What PLACES and RESOURCES on/off campus did you use to work on the project?

April 2015 Non-Scaled Questions

- Which college and department are you from?
- Which course are you enrolled in?
- What year are you in school?
- What is your gender?
- How useful was the experience in this class and/or participating in this project overall for you as a student? Please explain and give specific examples.
- How does this type of experience compare with your other BYU learning experiences? What are the strengths and weaknesses of this approach?

- How did the space and location for the class (in the library) contribute to or detract from the learning experience? Please give specific examples.
- How can we improve the usefulness of the space where the class was taught and of the experience itself?
- What did you learn, if anything, this semester, related to your content area? Please give specific examples.
- What did you learn, if anything, this semester not related to your content area? For example, consider other content areas, or even non-content learning, such as how to be more creative, collaborative, etc. Please give specific examples.
- Outside of your instructors, did you work with or learn from anyone else to help you in this class? For example, consider librarians, other faculty or students from your department, outside professionals, etc. If so, please list who they were and what they helped you with.
- What PLACES and RESOURCES on/off campus did you use to work on the project?

September 2014 Non-Scaled Questions (Pre-course survey)

- Which college are you from?
- What year are you in school?
- What is your gender?
- What are your reasons for registering for this course? Please be specific.
- What do you hope to learn this semester in your content area (discipline)?
- Is there anything you hope to learn this semester not related to your content area? Please give specific examples.

December 2014 Non-Scaled Questions

- Which college and department are you from?
- What year are you in school?
- What is your gender?
- What course are you enrolled in?
- What other innovation or creativity courses have you taken? Please be specific—provide course number and semester if possible.
- How useful was the experience in this class and/or participating in this project overall for you as a student? Please explain and give specific examples.
- How does this type of experience compare with your other BYU learning experiences? What are the strengths and weaknesses of this approach?
- How did the space and location for the class (in the library) contribute to or detract from the learning experience? Please give specific examples.
- How can we improve the usefulness of the space where the class was taught and of the experience itself?
- What did you learn, if anything, this semester, related to your content area? Please give specific examples.
- What did you learn, if anything, this semester not related to your content area? For example, consider other content areas, or even non-content learning, such as how to be more creative, collaborative, etc. Please give specific examples.
- Outside of your instructors, did you work with or learn from anyone else to help you in this class? For example, consider librarians, other faculty or students from your department, outside professionals, etc. If so, please list who they were and what they helped you with.
- What PLACES and RESOURCES on/off campus did you use to work on the project?

September 2014 Non-scaled Questions (Pre-course survey)

- Which college are you from?
- What year are you in school?
- What is your gender?
- Which course are you enrolled in?
- Outside of this class, in what ways do you typically use the library and library services?
- What are your reasons for registering for this course? Please be specific.
- What do you hope to learn this semester in your content area (discipline)?
- Is there anything you hope to learn this semester not related to your content area? Please give specific examples.

Appendix D

Results of Scaled Survey Questions

Course Experience

Statement	n	M(SD)	min	max
I had a deep, personal motivation to do well on this project beyond just for my grade	103	4.15 (1.00)	1	5
I felt responsibility for my portion of this project and for making it as good as possible	103	4.45 (0.81)	1	5
I had freedom to make choices about the design of my portion of the project	103	4.17 (0.97)	1	5
I was able to choose the kind of role I played on the team and the kind of work I completed on the project	103	4.18 (0.96)	1	5
Prototyping helped us make the project more creative and of a higher quality	103	3.88 (0.99)	1	5
I felt like everyone in the group was on equal footing and authority	103	3.37 (1.27)	1	5
In this experience, I learned in part by critiquing the work of others	103	3.73 (1.06)	1	5
In this experience, I learned through the critiques others gave me	103	3.94 (0.93)	1	5
I felt like the instructor was a mentor and a consultant more than a typical teacher	103	4.17 (0.92)	1	5
I learned new things unrelated to my previous areas of expertise and interest.	103	4.2 (0.94)	1	5

Note. Students were asked to rate each statement on a scale of 1 – 5, with 1 meaning "strongly disagree" and 5 meaning "strongly agree."

Epstein Creativity Competencies Inventory

Statement	n	M(SD)	min	max
I only like tasks that have a high probability of success	105	3.15 (0.94)	2	5
I rarely change the decorations in my work environment	105	2.92 (1.09)	1	5
I plan to read books and articles from areas outside my specialty	105	4.18 (0.94)	1	5
I do not share my ideas with others	105	1.68 (0.79)	1	5
I only seek training within my specialty	104	1.85 (0.83)	1	4
I do not like to work on problems that have no solution	105	2.72 (1.11)	1	5
I am not afraid of failure	105	3.44 (1.08)	1	5
I do not need any more colleagues	104	1.96 (0.89)	1	5
I enjoy working with the same group of people all the time	104	2.74 (0.92)	1	5

Note. Students were asked to rate each statement on a scale of 1 – 5, with one meaning "strongly disagree" and five meaning "strongly agree."

Runco Ideational Behavior Scale

Statement	n	M(SD)	min	max
I come up with a lot of ideas or solutions to problems	96	4.2 (0.76)	1	5
I like to play around with ideas for the fun of it	96	4.26 (0.73)	1	5
I enjoy having leeway in the things I do and room to make up my own mind	96	4.41 (0.72)	1	5
I would take a college course based on original ideas	96	4.16 (0.99)	1	5
I am able to think about things intensely for many hours	96	3.86 (0.99)	1	5
Sometimes I get so interested in a new idea that I forget about other things I should be doing	96	4.2 (0.79)	2	5
I often find that one of my ideas has led me to other ideas which have led me to other ideas, and I end up with an idea and do not know where it came from	96	4.05 (0.85)	1	5
I am able to think up answers that haven't already been figured out	94	3.96 (0.77)	1	5
I am good at combining ideas that others have not tried	95	4.14 (0.77)	1	5
Friends ask me to help them think of ideas and solutions	95	4.11 (0.81)	1	5
I have ideas about new inventions or about how to improve things	94	3.97 (0.85)	1	5
I have a good imagination	95	4.28 (0.81)	1	5
I feel I could lead a future project using a similar creative process to that used in this class	94	4.06 (1.00)	1	5

Note. Students were asked to rate each statement on a scale of 1 – 5, with one meaning "strongly disagree" and five meaning "strongly agree."