ACTIVITY, CREATIVITY, AND DESIGN: MODELING AND ASSESSING STUDENT DEVELOPMENT IN A PROJECT-BASED COURSE

by

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(Under the Direction of Lloyd P. Rieber)

ABSTRACT

The development of creativity and design ability in a group of undergraduate students enrolled in a design course were explored in this study. A review of literature was used to develop a coding scheme that integrated the domains of creativity, design, and activity theory which was then applied to content analysis (Hsieh & Shannon, 2005). This study used a mixed methods research design and an activity system analysis (Engeström, 2014; Jonassen, 2002). Participant surveys, design journals, and interviews were used to assess the students' design thinking traits during the 15-week course duration. The overarching finding of this study was a description of how a community emerged among the students and instructor. This community acted as a collective design tool to help the students expand their design creativity. The data supporting this finding were as follows: (1) high levels of learner autonomy supported participants' motivation; (2) the course community provided extended time and opportunities for practice; and (3) participants' final reflections centered on experience within the community and newly felt *creative agency* (Karwowski & Beghetto, 2018; Royalty et al., 2014). How this occurred is discussed, a five-factor model of the course activity system is proposed, and an assessment instrument for similar courses is provided. Guidelines for the design and implementation of similar courses are proposed, and suggestions for continued research are offered.

INDEX WORDS: design creativity, design thinking, creativity, creative agency, project-based learning, constructionism, activity theory, higher education, content analysis

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For Mildred, who lit fires and read to me at night.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

New ideas cannot be Googled, and yet increasingly complex, ill-defined, or wicked problems demand them. Can an ability to generate creative and innovative ideas be learned, and is there space for this kind of generalized design creativity in higher education, where recent trends have been in the direction of *vocationalism*, i.e., explicitly occupational degrees (Grubb & Lazerson, 2005)? These value-oriented questions are subject to debate, but if there is agreement that creativity and innovation are important student outcomes in higher education, then the next question is, what methods work for developing these abilities for college undergraduates? Moreover, is there any evidence that the current state of higher education needs to change at all?

Using a consumer-based approach for the assessment of post-secondary education, Strada Education Network and Gallup, Inc. (2018) aimed to determine how the quality and value of college experience was perceived by working adults in the United States who ranged from 18 to 65 years old and had varying levels of college degree attainment. Beliefs of "education relevance" (p. 2) were operationalized via the following two statements: (a) *The courses you took are directly relevant to what you do at work,* and (b) *You learned important skills during your education program that you use in your day-to-day life*. Five-point Likert-response scales were used to create an aggregate "relevance score" (p. 2), ranging from two to ten. A value of two was *strongly disagree with both items,* and a value of 10 was *strongly agree with both items*. In 2016, telephone surveys were used to gather survey data from a national sample of 110,481 working adults in America. A touted key finding was, "Only 26% of working U.S. adults with college experience strongly agree that their education is relevant to their work and day-to-day life" (p. 3). At face value, this statistic might seem alarming.

Considering that people born in the United States between 1957-64 held an average of 12.3 jobs in their lifetimes (Bureau of Labor Statistics, 2019b), and that median job tenure for all workers in the United States ranged from 3.5 years in 1983 to 4.6 years in 2014 (Pew Research Center, 2016) it comes as no surprise that college coursework did not "strongly" and "directly" correlate with job tasks. It is not reasonable to expect a direct correlation between course work and job tasks when workers so frequently shift jobs during their lifetimes. Furthermore, the initial five-point Likert scales were converted to 10-point scales, and the attention-grabbing 26% statistic reported as a top finding reflected only those responses that made the highest possible selections for both survey items. If counting responses that selected values seven through 10, the percentage is 63%, and when tallying values six through 10, the percentage becomes 75%. Filtering data in this way and the item wordings confound answering the original questions of quality and value while also dramatizing the misleading results.

Results from this Strada Education Network and Gallup, Inc. (2018) survey were used to recommend increased occupational emphasis in higher education, but Roksa and Levey's (2010) analysis of data collected by the National Longitudinal Survey Program (2005) showed that while occupationally specific majors correlated with higher status entry-level positions, they also had lower growth over time—a pattern that was similar but less pronounced with their earnings. Furthermore, students earning more generalized credentials correlated with lower status entry-level positions but high growth over time. Grosemans, Coertjens, and Kyndt (2017) conducted a systematic review to explore the relationship between what is learned in higher education and the resulting fit with the job market. They found "theoretical knowledge, communication, problem-solving, and learning skills" (p. 67) to be educational areas most emphasized—and that across employers, educators, and graduates, *generic competencies* were valued the most. The debate over the role of learning in higher education need not be reduced to either the specific or the general, and the point here is that the issue is not clear cut. As Grubb and Lazerson (2005) argue, the way forward is likely somewhere between the two extremes.

Uncertainty and problems not amenable to solution-by-algorithm or an internet search inspired the modern field of design, and particularly the strand of design creativity (Rauth, Köppen, Jobst, & Meinel, 2010). In the later part of the 1900s, the need to think beyond established parameters posed sharp challenges to the nascent field of information science (Kunz & Rittel, 1972), which spawned the post-modern strands of design literature, which evolved from a need to manage complexity and improve the world for a growing and diverse population (Rittel & Webber, 1973). Dewey's (1917) philosophy laid the groundwork that foreshadowed this design movement when he wrote, “In a complicated and perverse world, action which is not informed with vision, imagination, and reflection, is more likely to increase confusion and conflict that to straighten things out" (p. 65). Design, as a discipline, emerged to grapple with social, economic, and environmental upheavals left in the wake of the industrial revolution.

Within the design literature, an early call to integrate design as part of general education was articulated when Archer (1979) proposed design as a “third area in education” (p. 18) to connect the established domains of the science and humanities. Buchanan's (1992) proposal elaborated this line of thought with *design thinking* as a generally practiced liberal art as “new integrations of signs, things, actions, and environments that address the concrete needs and values of human being in diverse circumstances” (p. 21). In the past decade, there has been an overall growing trend for undergraduate education in design across large and small institutions, but Ilhan (2017) also warned that design education was moving out of larger doctoral/research universities and into smaller institutions. Given the scale at which larger research universities operate, the diminishing effect on design education was amplified.

Learning to have and develop new ideas is not supported by a mix of education, rigid standards, and conformity. When Eleanor Duckworth (1987) wrote about her experience with a science program for children in Africa, she described a curriculum characterized by the unexpected. Rather than teachers and students following lockstep procedures from booklets, they would formulate their own learning activities based on real things of interest to them. Instructional guidelines would be open-ended, allowing teachers and their students the freedom to be excited and to learn. She proposed two guidelines for creating conditions for this to happen:

> One is being able to accept children's ideas. The other is providing a setting that suggests wonderful ideas to children—different ideas to different children—as they are caught up in intellectual problems that are real to them. (p. 7)

Learning to have or not have new ideas can be both encouraged and discouraged. The creativity literature suggests this is the case in schools (Runco, 2007a) and in professional contexts (Amabile & Pratt, 2016). And, there is an overwhelming amount of research that proposes all people have creative potential and that it can be developed with practice (Daly, McKilligan, Leahy, & Seifert, 2019; Daly, Mosyjowski, & Seifert, 2019; Kleibeuker et al., 2017; Runco, 2007b; Scott, Leritz, & Mumford, 2004; Torrance, 1972). If design creativity is desired, then the design of learning environments might be orient toward generic competencies that support creativity and design ability.

Returning to Ilhan's (2017) analysis of undergraduate design education, the decline of design education in larger research universities was characterized as "somewhat alarming if design disciplines want to move away from a traditional, skill-based education toward a more knowledge-based orientation" (p. 28). The relegation of design education to its traditional role of technical skill support overlooks the value Dewey, Archer, Buchanon, and Duckworth placed upon the experiential, interdisciplinary, and human-centered discipline of active learning and its variant, design thinking. Learning the technical skills for operating technology is important but limited, and steering the use of technology with creative and innovative ideas is of a higher order.

Bringing agency and design creativity to the use of technology might help people cultivate ideas and use technology in innovative ways. As Alan Kay once noted during an interview, “The important thing here is that the music is not *in the piano*. And knowledge and edification is not *in the computer*. The computer is simply an instrument whose music is ideas” (Kongshem, 2003, "What do you think of the current trend toward one-to-one computing," para. 5). The ideas that inform tool use of any kind are what truly creates, or designs, value. Higher education is well-positioned to offer learners opportunities to practice and develop creative design ability. Design and practical activity might support interdisciplinary learning collectives that allow learners to practice applying what they have learned beyond the boundaries of their specializations. This would expand the context of *vocationalism*, a trend in higher education which Grubb and Lazerson (2005) describe as undeniable, with more generally applicable skills associated with design creativity.

The Evolution of Job Tasks

Americans are split along partisan lines as to what the main purpose of college should be, but the majority “view workforce-relevant skills and knowledge as more important than personal and intellectual growth” (Pew Research Center, 2016, p. 77). This poses the question of what is it that college graduates *do* that makes them valuable in the workplace? This is what Autor, Levy, and Murnane (2003) asked to begin the development of an economic model to predict which job tasks might be most resistant to computerization. Citing an early example of automated work (the Jacquard loom, 1801) and noting the trillionfold decrease in the cost of computing power since, the researchers used the concept of job task descriptors (and not educational credentials) to explore the nature of changes in work due to computerization. To better understand different types of work activity, Autor et al. (2003) distinguished between *manual*, *cognitive*, *routine,* and *non-routine* tasks.

Manual tasks required a physical performance of workers, such as monitoring equipment or guiding assembly. Cognitive tasks involved degrees of information processing that required workers to analyze and interact with information. Manual and cognitive tasks were either routine or non-routine. Routine tasks are tasks that can be "…accomplished by machines following explicit programmed rules" (Autor et al., 2003, p. 1283), whereas non-routine tasks are tasks guided by rules that are unclear and therefore not reducible to computer code.

As computational power became less expensive and more sophisticated computers increasingly completed routine job tasks and augmented non-routine job tasks typically performed by the college-educated labor pool. Examples of non-routine tasks are those "…demanding flexibility, creativity, generalized problem-solving, and complex communications—what we call nonroutine cognitive tasks—do not (yet) lend themselves to computerization [Bresnahan 1999]" (p. 1284).

Autor et al. (2003) posed another question, "Which of these tasks can be performed by a computer" (p. 1282)? Based on this question, they developed their four-quadrant task model that distinguished between routine tasks, non-routine tasks, analytic and interactive tasks, and manual tasks. Table 1 is reprinted from Autor et al. (2003) and shows which workplace tasks were the most and the least likely to be computerized. Predictions from the table are coming to pass as routine tasks involving repetitive assembly (e.g., assembly line workers), repetitive customer service (e.g., cashiers), and record-keeping (e.g., bookkeepers) are being carried out by robots and computer software. Some of the non-routine tasks cognitive tasks resistant to computerization, such as driving, are now being accomplished by autonomous vehicles. Of course, back in 2003, these authors were not able to factor in the more recent development in computer programming, such as machine learning—where it is software and not people that generate task rules.

Table 1

The Task Model for the Impact of Computerization on Workplace Tasks

	Routine tasks	Non-routine tasks
	Analytic and interactive tasks (cognitive)	
Examples	• Record-keeping • Calculation • Repetitive customer service (e.g., bank teller)	• Forming/testing hypothesis • Medical diagnosis • Legal writing • Persuading/selling • Managing others
Computer impact	• Substantial substitution	• Strong complementarities
	Manual tasks	
Examples	• Picking or sorting • Repetitive assembly	• Janitorial services • Truck driving
Computer impact	• Substantial substitution	• Limited opportunities for substitution or complementarity

Note: From "The Skill Content of Recent Technological Change: An Empirical Exploration." by D. H. Autor, F. Levy, and R. J. Murnane, 2003, The Quarterly Journal of Economics, 118, p. 1286. Copyright 2003 by Oxford University Press. Reprinted with permission.

Autor et al.'s (2003) predictive task model was updated and revised by Frey and Osborne (2017) to reflect the growth of powerful algorithms that turn "non-routine tasks into well-defined problems" (p. 259). Their revised model is built from a "technological capabilities point of view" (p. 255) and uses the engineering bottlenecks that pose barriers to the computerization of job tasks to predict new task categories that will resist computerization in the coming decades. Data for their model was taken from the U.S. Department of Labor's 2010 O*NET online and freely available database of occupational information. Their analysis discussed the convergence of machine learning, data mining, machine vision, computational statistics, artificial intelligence, mobile robotics, and the sophisticated analysis of big data.

Task categories resistant to computerization. Frey and Osborne (2017) rank-ordered 702 different occupations based on their probability of being computerized and assigned each occupation to either a low, medium or high-risk category. 47% of the total US workforce was in the high-risk category, meaning those jobs are predicted to be automated “relatively soon, perhaps over the next decade or two” (p. 268). The authors predicted low-skill, low-pay jobs to be most at risk and high-skill, high pay jobs to be least at risk.

A lull in computerization characterized as a “technological plateau” (Frey & Osborne (2017), p. 265) would be due to occupations that required high degrees of perceptual, creative, and social intelligence. The occupations most resistant to full automation required high degrees of creative and social intelligence. Social intelligence was associated with CEOs, managers, educators, health care workers, and those working in arts and media. Creative intelligence was associated with occupations in engineering and science. The predictions were dependent on variables such as the availability of cheap labor, the level of political activism surrounding the issue of computerization, and the variations within each occupation in response to computerization.

The three new task categories predicted to be most resistant to computerization for the next decade or two are *perception and manipulation*, *creative intelligence,* and *social intelligence* (Frey & Osborne, 2017). The authors define perception and manipulation tasks as involving the handling of irregular objects, the navigation of unstructured work environments, the ability to recover from failure, and the planning of action sequences to move objects. Creative intelligence tasks involve the generation of novel ideas that add value to a given context. Computers can easily be programmed to generate novelty, but a consensus among people is needed to determine the value of computer-generated novelty. Social intelligence tasks involve real-time recognition of human emotion, responses to human emotion, and the ability to use common sense to respond to human social settings.

Of the three categories, perception and manipulation tasks were most susceptible to computerization due to advances in machine learning, but tasks within the creativity and social categories were much less at risk. Therefore, "generalist occupations requiring knowledge of human heuristics, and specialist occupations involving the development of novel ideas and artifacts, are the least susceptible to computerisation" (Frey & Osborne, 2017, p. 266).

There are other predictions about how work will change. Projections from the Bureau of Labor Statistics (2019) indicate the aging U.S. population and labor force will characterize much of the change in U.S. employment for the coming decade. The healthcare, social assistance, private educational services, construction, leisure/hospitality, and professional business services industries are predicted to have the most growth. The most occupational growth was predicted to be in healthcare occupations, software and cybersecurity, and small scale but rapid growth for work installing and maintaining solar and wind technologies. These projections provide added context and help frame the qualities other researchers predict will be broadly valuable within and across these growing industries and occupations.

Autor et al. (2003) and Frey and Osborne (2017) both emphasized an increasing need for college-educated workers. Whereas the recent labor market trend has been a hollowing out of middle-income jobs with the polarization and growth of both low paying and high paying jobs, the authors' new model predicts "computerisation will mainly substitute for low-skill and low-wage jobs in the near future" (p. 267). As those low-skill and low-wage jobs disappear, workers will need to find new jobs but, "For workers to win the race, however, they will have to acquire creative and social skills" (p. 269). As computers continue to perform more job tasks traditionally carried out by people, abilities that rely on creative and social intelligence will become more important to have across all occupations. As educational systems strive to meet these needs, what will they do?

Project-based Learning for Tool Learning, Creativity, and Socialization

Frey and Osborne's (2017) suggestion that perception and manipulation, creative intelligence, and social intelligence were the least likely task categories to be computerized is a reminder that humans are creative, social beings with sophisticated tool capabilities. What learning environments have been shown to facilitate development within and across these broad categories that make humans unique, at least in comparison to what computers cannot yet do?

A content-independent course design conceptually framed as active learning can afford learners opportunities for the practice of design creativity and social skills across any subject matter and as interdisciplinary groups. Condliffe's (2016) review of the project-based learning literature suggested projects can facilitate the development of 21st-century skills such as creativity and social intelligence. While there is no universally agreed-upon specification for project-based learning in the literature, Thomas (2000) identified “centrality, driving questions, constructive investigations, autonomy, and realism” (p. 2) as five essential criteria project work must meet for it to be considered project-based learning.

According to Thomas (2000), these criteria had the following qualities. Projects should be central to the course and not smaller components of it—they *are* the course and orient all student activity and development. As project-based learning is an inquiry strategy, projects should use driving questions crafted according to the subject matter and learning goals of the course.

Project work also needs to involve the learning of new skills, and therefore projects should involve transformations as opposed to simply carrying out of familiar activity. Also, projects should be student-driven and not predetermined. Lastly, for project work to meet the criteria for project-based learning, projects should relate to students’ real-life challenges and focus on authentic problems.

Since project-based learning makes it necessary for students to think of project ideas and develop them, project work affords opportunities for creativity and practice of the skills and attitudes related to it. Students can gain experience with aspects of creativity that have been researched in the creativity and design literature. Extended project work affords learners opportunities to make design choices that happen to reflect well-researched aspects of creativity, some of which are described in Table 2.

Table 2

Creativity Topics Relevant to Project-Based Learning

Creativity topic	Description	Supporting research
Problem-finding	Identification of the problem is the first, and some say the most important part of creative problem-solving.	Csikszentmihalyi & Getzels, 1971; Jia et al., 2017
Tolerance of ambiguity	The ability to remain open to possible solutions and resist premature closure is linked with high-quality creative solutions.	Beheshti, 1993; Frenkel-Brunswik, 1949; Leifer & Steinert, 2014; Macdonald, 1970; Tracey & Hutchinson, 2016; Zenasni, Besançon, & Lubart, 2008
Divergent thinking	Divergent thinking is the ability to generate an ideational pool of many possible options.	Acar & Runco, 2017; Baer, 1996; Basadur, 1995; Guilford, 1950
Convergent thinking	Convergent thinking is the ability to select from a large ideational pool of options optimally.	Acar & Runco, 2017; J. Baer, 1996; M. Basadur, 1995; Cropley, 2006; Guilford, 1950
Creative process	The creative process involves multiple stages of conscious and unconscious thought and occurs across an extended period.	Cross, 1997; Dorst & Cross, 2001; Goslin-Jones & Richards, 2018; Torrance, 1968; Wallas, 1926
Attitudes that support creativity	Creative behavior can be encouraged or discouraged by attitudes and values at work in the learning context.	Amabile, Barsade, Mueller, & Staw, 2005; Anderson, 2018; Beghetto, 2006; Crilly, 2015; Dweck, 2006; Gajda, Karwowski, & Beghetto, 2017; Kelley & Kelley, 2013; Witt & Beorkrem, 1989

It is important that students can learn about their creative potential, the creative potential in others, and how to use and develop it—because demystifying creativity is the initial step that helps students conceptualize and apply it (Hokanson, 2018; Runco, 2007; Torrance, 1961).

Project-based learning can also support the development of social intelligence. Research has shown it supports 21st-century competencies in the cognitive, intrapersonal, and interpersonal domains (Hilton, 2015; Pellegrino & Hilton, 2012). Since project-based learning involves publicly sharable projects and offers many opportunities for doing activities as a learning group, opportunities to learn about and improve social intelligence are inherent to project work. The design of project-based learning can involve scaffolds that support creativity and design ability—this is an area of instructional design that has been developed to support constructivist learning environments (Clinton & Rieber, 2010; Hannafin & Rieber, 1989; Hannafin, Hill, Land, & Lee, 2014; Hill & Hannafin, 2007; Jonassen, 1994; Lebow, 1993).

Recent trends in higher education have been to combine project-based learning with design thinking. In the higher education context Blizzard et al. (2015), Dym, Agogino, Eris, Frey, and Leifer (2005), and Lande (2016) used design thinking to support project-based learning—a promising direction for the support and understanding of the creative design process and learning. In the high-school context, Yeager et al. (2016) used design thinking to "to make psychological intervention materials more broadly applicable to students" (p. 377) that served to facilitate a growth mindset intervention for ninth-grade high school students in the United States and Canada. Their work was followed by a similarly designed yet more compact online intervention with approximately 12,500 high school students across the United States. Fixed mindset beliefs and grade point averages were shown to improve as a result of the intervention (Yeager et al., 2019). This suggests that the outcomes of project work are not just the projects, but the psychological changes that were associated with learning about and doing design thinking.

Project-based learning has a history of positive impact on learner motivation and cognitive engagement (Blumenfeld et al., 1991; Clinton & Rieber, 2010; Dewey, 1938; Papert, 1993, 2001; Papert & Harel, 1991; Patri, 1917; Piaget, 1973) and enjoys support from an extensive body of diverse research that goes back many years, e.g., Dewey (1938). Lave and Wenger's (1991) situated learning theory emphasized the learning value of activity within context. Brown, Collins, and Duguid (1989) elaborated their situated learning theory into situated cognition and cognitive apprenticeships. Kolb's (2014) experiential learning theory emphasizes activity, or process, over outcome-oriented goals, which relate to epistemologies of behaviorism and idealism. Kolb claims that outcome-oriented learning can be a kind of non-learning. Perhaps the most focused theory of learning to support a project-based learning approach to instruction is constructionism, as described by Papert and Harel (1991). Project-based learning remains a popular instructional design with students and teachers across all school levels (Condliffe, 2017; Kokotsaki, Menzies, & Wiggins, 2016; Larmer, 2016; Larmer, Mergendoller, & Boss, 2015; Quint & Condliffe, 2018; Sasson, Yehuda, & Malkinson, 2018).

For all of its strengths, project-based learning is challenging to design, implement, and assess (Blumenfeld et al., 1991; Condliffe, 2016; Conley & Darling-Hammond, 2013; Dixon-Román & Gergen, 2013; Royalty et al., 2014; Thomas, 2000). Researchers are working to identify assessment methods that can evaluate the socio-cultural-historical development that often characterizes practical learning activities. For example, The Gordon Commission analyzed assessment practices in the United States and made recommendations to "improve pedagogical practice, educational measurement and student achievement" (ETS Research, 2019). According to Dixon-Román and Gergen, (2013), members of the commission discussed emerging approaches to measurement in relation to the "socio-cultural and situative perspectives on learning, knowledge-making, and human development" (p. 14) during the past several decades that "…have been informed, for example, by the works of Lev Vygotsky, cultural psychology, and educational developments in sociology, anthropology, and linguistics" (p.14).

Rigorous and empirically-based assessment of project-based learning has been a longstanding challenge, and the need for it was stated years ago. For example:

> In the case of Project-Based Learning, the lack of an overarching theory or model of PBL, the paucity of research devoted to PBL methods, and the gaps in our knowledge about the relative effectiveness of teacher-initiated projects create an unusual and vulnerable situation for PBL practitioners. (Thomas, 2000, p. 38)

This problem of project-based learning and assessment is persistent, and Condliffe's (2016) more recent review of the project-based learning literature reiterates Thomas' (2000) observation.

Within the project-based learning literature, the emphasis is on K-12 contexts, and there is a comparative lack of literature concerning the context of higher education. Most project-based learning research considers adults and higher education as an aside if at all (Blumenfeld et al., 1991; Condliffe, 2016; Kokotsaki et al., 2016; Thomas, 2000). Despite the emphasis on K-12 contexts, the literature surrounding project-based learning in higher education is growing and is most prominent in the domain of engineering (Blizzard, Klotz, Pradhan, & Dukes, 2012; Dym, Agogino, Eris, Frey, & Leifer, 2005; Gibbes & Carson, 2014; Kokotsaki, Menzies, & Wiggins, 2016; Ruikar & Demian, 2013). More research into how project-based learning works with adult populations might lead to improvements with its application in higher education contexts.

Project-based learning also supports deeper learning, which involves the active use of multiple areas of knowledge and the deep transfer of learning (Pellegrino & Hilton, 2012). The practical activity of project work has the potential to connect learners' preexisting knowledge with new contexts, allowing them to apply what they learn and in novel contexts. Norman and Klemmer (2014) argued for a change in design education and suggested the institutional norms cemented into university structures elevate the specialist over the generalist. Project-based learning as an instructional strategy has the potential for the general application of specialized knowledge, and it also affords opportunities for the practice of design creativity within social contexts.

Design as Education

The activity of design as a fun, engaging, and effective way to learn has been theorized, practiced, and researched for years (Archer, 1979a; Buchanan, 1992; Cross, 2018b; Dewey, 1910; Dunne & Martin, 2006; Papert, 1993; Rieber, Luke, & Smith, 1998; Simon, 1969). Archer (1979) noted that the educational role of "making and doing" was not new and traced its development from Plato through the Renaissance and to the craft guilds. He suggested the humanities came to dominate general education as a result of continuous sociocultural and historical pressures.

> It is a curious twist of fortunes that when the craft guilds lost their general educational role somewhere between the fourteenth and eighteenth centuries, it was the rather narrow, specialist, bookish universities, academies and schools which had been set up to train priests to read and translate the scriptures which became the guardians of what we now call general education. (p. 18)

His concern was that there was no distinct area within educational institutions to represent the "collected experience of doing and making…[which] comprises the ideas which govern the nature of every sort of artefact produced, used and valued by man" (p. 19).

It was from this perspective he argued for a "third area in education...[as]...an approach to knowledge, and of a manner of knowing, which is distinct from those of Science and the Humanities...the collected body of practical knowledge based upon sensibility, invention, validation and implementation" (p. 20). He ascribed *notation* as the essential language of Science, *natural language* as the essential language of the Humanities, and *modeling* as the essential language of design. Modeling involved multiple modes of representations to "capture, analyze, explore and transmit" (p. 20) ideas. To literacy and numeracy, he added the term "design awareness...[which means] 'the ability to understand and handle those ideas which are expressed through the medium of doing and making'" (p. 20). He held that modern society needed "competence in something else besides literacy and numeracy" (p. 18) and an awareness of ecological, environmental, and urban design problems.

The inclusion of design as a foundational area of education could support the practical application of knowledge because "In Design, the repository of knowledge is not only the material culture and the content of the museums but also the executive skills of the doer and maker" (p. 20). Archer’s ideas remain compelling and offer a framework for thinking about and redesigning educational systems today. Figure 1 shows his proposal to integrate the humanities, sciences, and design as the three overarching areas of educational institutions.

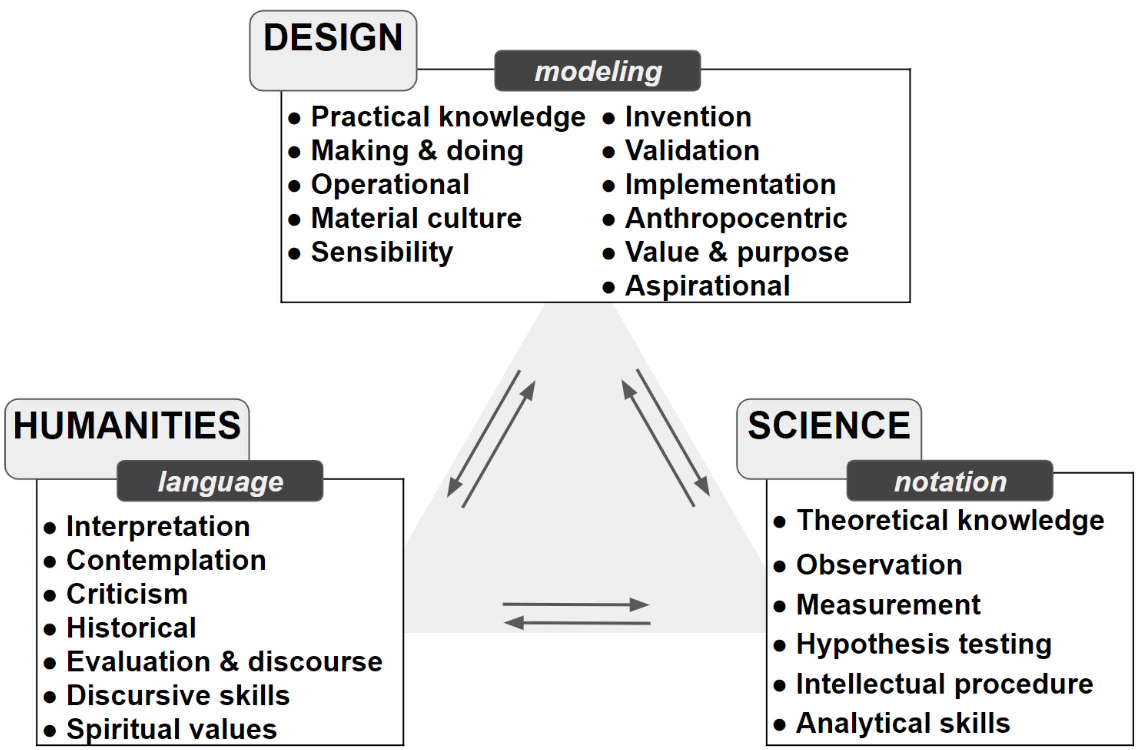

Figure 1. Archer’s (1979) three proposed main areas of education and their qualities. Adapted from "The Three Rs." by L. B. Archer, 1979, Design Studies, 1, p. 20.

Design is a way of applying knowledge within an authentic context that affords multiple modes of expression that can complement, connect, and *enliven* the numbers and words that form the two pillars of the sciences and humanities. Archer understood how powerful design could be for learning when used to integrate and apply knowledge.

These days, affordable and far-reaching technology allows everyone to be a designer, and the traditional gatekeepers of design and knowledge are either adapting to the new landscape or going extinct. von Hippel (2005) observed that people are increasingly innovating product design by taking ownership of the design process that once used to be the exclusive domain of manufacturers. Brown's (2008) popularization of the term *design thinking* resulted in the growth of human-centered design practices in business and higher education that continues to grow. People are clearly interested in doing design, and they not waiting on industry or educational institutions to lead the way. When given the means, people are increasingly designing their own products and learning paths.

Design thinking is a popularized way of applying design to educational contexts and might be thought of as "applied creativity," a term borrowed from Parnes (1972). Design thinking offers a collection of methods and attitudes aimed at achieving creative outcomes for people and the problems they experience. As a form of organizational creativity (Kozbelt, Beghetto, & Runco, 2010), design thinking has been used in the workplace to innovate, and also for course design within higher education. It is popular with engineering educators (Dym et al., 2005; Lande, 2016), and is now being used more often in the liberal arts (Ejsing-Duun & Skovbjerg, 2018; Ioannou, 2018; Magnussen & Sørensen, 2014; Rauth et al., 2010). Wells (2013) advocated for using design thinking as part of a strategy for gaining technological literacy. Design thinking might be considered as a conceptual framework that helps leaners and instructors be more creative and innovative in their work.

The Context of Higher Education

Florida (2014) argued that people need to be creative to thrive in the post-industrial world. The list of 21[st]-century skills identified by The Partnership for 21st Century Learning (2015) includes *critical thinking*, *communication, collaboration*, and *creativity* as core learning and innovation skills. Although 21[st]-century skills are essential for students to learn, there is no consensus as to how they are "best" learned (Rotherham & Willingham, 2009). Moreover, the assessment of these skills is challenging when standardized testing fails to measure them (Bell, 2010). There is no established consensus for teaching these innovation skills, although research suggests that the cultivation of creative design skills leads to innovation (Brown & Kuratko, 2015).

Worwood and Plucker (2017) noted that "…certain stages of design thinking rely heavily on specific creative thinking skills, which tend to be domain general" (p. 92) and suggested design thinking as a structure for project-based learning. Still, there is resistance to using design thinking within academic and corporate contexts (Leifer & Meinel, 2015, p. 3.) The reluctance could be due to the new assessment methods required, the lack of consensus about how to teach 21[st] Century Skills, or the challenge of redesigning courses to be project-based. Nonetheless, design thinking can be used to support creative practice in project-based learning environments.

Activity Theory to Contextualize Projects, Design, and Creativity

Micheli et al.'s (2019) review of the design thinking literature emphasized a need for more rigorous assessment of design thinking, "because empirical evidence of the impact of design thinking is still lacking, it is difficult to specify the timing, level, resource intensity, and intended outcomes of its deployment" (p. 144). These are similar concerns to the ones raised regarding project-based learning.

Condliffe's (2017) review of project-based learning literature concluded with a call to strengthen project-based learning research. More focus was needed on the context and the effects of project-based learning models, technology, and teacher beliefs on implementation efforts. The need to develop common, testable design principles for project-based learning across multiple contexts was emphasized. This included greater attention toward intrapersonal and interpersonal competencies, project-based learning's effectiveness across different subject areas, and how project-based learning works for underserved student populations. Many contextual factors surround using project work to support learning, design, and creativity. If the context of project-based learning is a needed focus for future research, a systems approach could prove beneficial.

Activity theory is a systems-based approach to the analysis of human development that originated with Vygotsky's developmental research and is theoretically situated as socio-constructivism. Activity theory's epistemological orientation categorizes it with other learning theories and philosophies that view "learning [as] less about acquiring information or transmitting existing ideas or values, than it is about collectively designing a world in which it is worth living" (Ackermann, 2004, pp. 2–3). This developmental perspective is appropriate for analyzing learning environments built around project-based learning undertaken by groups. Vygotsky's ideas have been extended and elaborated as an analytical framework (Engeström, 2014) to guide a systems analysis of practical activity and human development—sometimes in tandem with formative intervention research.

As a systems-based analytical framework, activity theory has been used to analyze human learning activities (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002; Detlor, Hupfer, & Smith, 2016), students' design process (Cash, Hicks, & Culley, 2015), information systems (Crawford & Hasan, 2006), health care services (Engeström, 2001), to design and research formative interventions (Sannino, Engeström, & Lemos, 2016), and to generate design guidelines for constructivist learning environments (Jonassen & Rohrer-Murphy, 1999). Activity theory's interoperability as a generic analytical framework allows it to be combined with other learning theories and used across multiple contexts. It's historical (i.e., longitudinal) methodological orientation seeks to identify developmental patterns of activity and to suggest signature models of activity (Engeström, 2014).

An interesting and recent application of activity theory has been as a design and research tool for formative interventions (Sannino et al., 2016). In this case, researchers work with participants to facilitate transformative agency and generative solutions to authentic problems. These interventions occur across extended periods of time where participants address locally situated problems and carry out a collective practical activity that results in “breaking away from the given frame of action and taking the initiative to transform it” (p. 603). This learner-centered learning environment aligns with the practice of human-centered design (van der Bijl-Brouwer & Dorst, 2017), the concept of *frame creation* (Dorst, 2015), and Dorst's (2011) proposal of frame creation as a “core” (p. 531) design practice. This convergence of ideas suggests activity theory is a good fit for investigations of project work, design, and creativity.

Design creativity and project-based learning are still newly emerging learning activities in higher education (Blizzard et al., 2015; Coso Strong, Lande, & Adams, 2019; Dym et al., 2005; Taboada & Coombs, 2014), and research into how courses might support the development of creative design ability is lacking (Daly, Mosyjowski, et al., 2019). Given the emergent quality of project-based learning to support design creativity in higher education, a strategy-oriented toward exploring and understanding what occurs in courses of this kind and in this context seems reasonable. Additionally, it is important to prepare for such exploratory research (Stebbins, 2001) by first gathering insights the literature has to offer on the subjects of creativity and design. Within this context, it would be interesting to know what the project experience is like from the student perspective in order to identify areas for future research and propose recommendations and models regarding similar learning environments.

Research Questions

The purpose of this study was to gain a better understanding of how creative design ability developed for undergraduate students as they identified and solved everyday problems. The primary research questions were:

1. How does creative design ability develop for an interdisciplinary group of undergraduate students as they identify, design, and deliver final projects to solve everyday problems?
2. What contextual elements shape students' creative design process?
3. What evidence of creativity and design thinking exists in students' developmental process?

This research provides an example for those interested in designing, implementing, and researching interventions in higher education contexts oriented around project-based learning, design, and creativity. It is intended as an initial phase of research to identify what contextual factors emerge and play a role in the shaping of students' creative design ability. As Alan Kay suggested in a keynote address to stakeholders in higher education, "The best way to predict the future is to invent it" (Kay, 2007). As active, experiential, and project-based learning strategies are increasingly used to support deeper learning in higher education contexts, a need emerges to understand what that looks like and how it happens as part of an overall plan for systematic evaluation and improvement of learning and instruction.

Gathering theoretical knowledge about creativity and design and next observing how students design and create are initial phases in the development of a systems-based model to inform the design of similar learning environments in higher education. Therefore, an informal review of the creativity and design literature precedes data collection and analysis. The contextual factors that emerged from this study will be discussed, and proposals regarding them will be made. Finally, a model will be proposed along with an assessment instrument and suggestions for future research.

CHAPTER 2

REVIEW OF LITERATURE

Preamble

Since this study used an activity system analysis to explore a project-based course for evidence of creativity and design thinking, knowledge of these areas was important. To this end, principles from the creativity, design, and activity theory literature were used to construct a coding scheme (Appendix A) that was applied to journal and interview texts collected for this study. Due to the length needed to accomplish this review, this preamble provides a brief orientation and summary of key ideas in this chapter.

When students do project-based learning they use their creativity to conceive, design, and deliver their ideas. Condliffe (2017) noted creativity as one of the "21st-century skills" that were broadly supported by project-based learning as an active learning approach that facilitated deeper learning. Pellegrino and Hilton's (2012) work to define *deeper learning* (also called meaningful learning) in relationship to 21st-century skills emphasized the broad use of cognitive competency clusters centered around (a) cognitive process and strategies, (b) knowledge, and (c) creativity. Deeper learning was defined as, "The process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations (i.e., transfer)" (p. 4). While project-based learning requires creativity, it also affords opportunities for the interconnected application of multiple types of knowledge and attitudes. In secondary and higher education project-based learning contexts, efforts to facilitate and assess creativity (Doppelt, 2009; Dym, 2005) and design thinking (Blizzard 2015) have led to calls for more research at the intersection of projects, design, and creativity.

Literature from the creativity domain is vast and extends across the four areas of (a) persons, (b) process, (c) press (environment), and (d) products (Rhodes,1961; Cramond). Research within each area is extensive, and it has been suggested an optimal approach toward creativity research might be an eclectic one (Runco, 2007). Csikszentmihalyi and Wolfe (2000) argued for a systems approach to creativity research due to the increasing need that individuals be able to “formulate new problems, come up with new solutions, and adapt readily to the new ideas of others” (p. 181). Persons, process, press (environment), and products offer a high-level mapping of creativity research. Consideration of these areas and their dimensions as contextual factors should improve the exploratory analysis of creativity as it occurs for students who practice creative design through their project work.

The “persons” area of creativity research involves personal characteristics and dimensions of creativity like motivation, cognition, and beliefs. Longstanding empirical research has suggested the simple awareness of creative potential and instructions to “be creative” promotes creative, specifically divergent thinking (Harrington, 1975). Research concerning the creative process suggests creativity can be understood in terms of a developmental series of stages and cognitive styles across extended periods (Basadur, 1995; Kaufman & Sternberg, 2019; Runco, 2007a; Wallas, 1926). Research surrounding “press,” or environmental pressures on creativity suggests dimensions of culture and attitudes can either encourage or discourage creative behavior (Amabile, 1983; Amabile & Pratt, 2016), and also includes findings concerning the physical environment’s impact on creative behavior (McCoy & Evans, 2002; Thoring, Desmet, & Badke-Schaub, 2018). Establishing criterion for the assessment of creative products is a major challenge for creativity research (Plucker, Makel, & Qian, 2019), but assessment methods involving social validation, or panels of judges, have been shown to work and be valuable (Amabile, 1982).

Research into creativity and the practice of design emerged during the same decade. Guilford's (1950) address to the American Psychological Association was a milestone that marked the start of the modern strand of creativity research. During the same period, the “design methods movement” (Broadbent, p. 3, 2003) began in 1950s West Germany. Within the design research domain, the early prominence of information theory and computer science (Simon, 1969) branched into more socially oriented design practices characterized by an emphasis on uncertainty and human-centered design methods. It was a human-centered approach toward product design (Brown, 2008) that began the ascendance of “design thinking” and its application in educational contexts (Rauth et al., 2010).

Some of the main characteristics of design found in the design literature were modeling, frame creation, and empathy. Bruce Archer, a prominent figure from the earlier period of design literature, suggested modeling was the “essential language of design” (Archer, 1979, p. 20). Related literature about modeling called it “one of the critical instruments of modern science” (Morrison and Morgan, 1999, p. 10) and “key to the design enterprise” (Jonassen, 2011, p. 148). Prototyping is a form of modeling extensively used in design and design thinking, which Rauth, Köppen, Jobst, and Meinel (2010) describe as a “culture of prototyping” (p. 3).

The use of abductive reasoning and particularly *frame creation* is another prominent construct from the design literature that has been called a “core practice that is particular to the designing disciplines” (Dorst, 2011, p. 531). Framing and reframing occur within the design process as practitioners engage with problem finding and align found problems with optimal solutions. Framing actions typically extend across the design process and can be seen as a co-evolution of the problem and solutions spaces (Dorst & Cross, 2001). Successful frame creation often requires a tolerance of ambiguity (Furnham & Marks, 2013; Rokeach, 1960) and resistance to premature closure (Basadur, 1994) that keep the problem-solution space open and flexible during much of the design process.

Runco suggested tolerance of ambiguity relates to the five-factor model of personality (Costa & McCrae 1999) and the trait of *openness*. The ability to manage uncertainty while working through ill-structured design problems (Jonassen, 2011) is associated with *creative self-efficacy* (Beghetto, 2006; Tierney & Farmer, 2002), *creative confidence* (Kelley & Kelley, 2013; Rauth et al., 2010; Royalty et al., 2014), and *creative agency* (Karwowski & Beghetto, 2018; Royalty et al., 2014). All of these creativity constructs are similar affective states found in the creativity and design literature and often cited as successful learner outcomes for educational interventions involving design thinking. As with modeling, frame creation interacts with multiple contextual factors.

Along with modeling (e.g., prototyping) and abductive reasoning (e.g., frame creation), empathy is another prominent component of design practices. Empathy (Kouprie & Visser, 2009) is used to achieve a human-centered approach toward design, and designers use various methods to focus design practice on people, their problems, and their needs. As one of the early and effective communicators of design thinking, Brown (2008) emphasized the importance of practicing empathy as a way of carrying out human-centered design, and Royalty, Oishi, and Roth (2014) called empathy a “core construct” (p, 81) in the practice of design thinking.

Design and design thinking have been used in higher education to support project-based learning courses, and the classic design discipline of engineering has been most active in reporting on efforts to blend design thinking with curriculum and course project work (Blizzard et al., 2015; D. H. Cropley, 2016; D. H. Cropley & Cropley, 2000; Dym et al., 2005; Lande, 2016). Dym et al., (2005) called for more efforts to facilitate and assess creativity as a component of the design process. Blizzard et al., (2015) developed a survey to measure design thinking traits to understand “who design thinkers are and what they care about” (p. 108). Beyond the field of engineering and into communication design, Ejsing-Duun and Skovbjerg (2018) used design to frame and research multiple modes of inquiry intended to develop students' knowledge of design practice, domain specialties, and societal issues. Archer's (1979) proposal for design as a "third area in education" (p. 18) appears to have persisted as these and other manifestations of design and learning suggest. The active, design-oriented, and project-based approaches to deeper learning support Perkins' (1986) suggestion that "knowledge is not just *like* design but *is* design in a quite straightforward and practical sense" (p. 2).

Exploring and assessing student development within project-based courses is methodologically challenging. Pellegrino and Hilton (2012) suggest that deeper learning outcomes involve the use of multiple skills and abilities. What research approach might account for these multiple contextual factors? Proceeding with recommendations from Csikszentmihalyi (1988) and Csikszentmihalyi and Wolfe (2000) that research into creativity and education involve a system-based approach, the analytical framework of activity theory (Engeström, 2014; Jonassen, 2002) was selected for its systems orientation and emphasis on the contextual meaning of practical activity.

The origins of activity theory are in the developmental research conducted by Vygotsky (1978) and his pupils. Their work resulted in a conceptual framework that delineated the practical activity of groups within a tool-mediated and socio-cultural context. Vygotsky formulated the concept of *the zone of proximal development* to frame and research the use of internally oriented signs (e.g., language, concepts) and externally oriented tools (e.g., physical or virtual instruments) within social contexts. Vygotsky also formulated *the functional method of double stimulation* as a research methodology oriented toward observations of tool use within problem-solving behavior. Leont'ev (1977) and Luria (1976) extended Vygotsky's concepts to include collective activity and cultural differences, respectively. Activity theory's holistic perspective and its emphasis on tools, groups, and culture offer a good fit for developmental research into project-based work in educational settings.

More recently, Engeström (2014) has elaborated activity theory and adapted Vygtosky's method of double stimulation to guide the design and implementation of formative intervention research (Sannino et al., 2016). This kind of research involves proposing a contradiction to participants and supporting them in their work to resolve it. Sometimes the researcher provides materials to support the participants' construction of instruments that address and resolve the initially proposed contradiction. Other times the participants generate their instruments on their own to address and resolve contradictions (e.g., ill-structured or wicked problems.) The process facilitates participants' developing the transformative agency needed to take ownership of the intervention and their learning to manage complexity and solve problems. With this kind of formative intervention research, the possibility exists that participants will take varying degrees of control of the intervention so that they iterate to reuse it for different problems in different contexts.

This application of activity theory as formative intervention research is especially relevant to project-based learning environments that grant learners high degrees of autonomy in their project work. Activity theory is not limited to this application—one of its strengths as a generic framework for analysis is its interoperability. For example, activity theory has been adapted and applied across field of human-computer interaction (HCI) (Kaptelinin & Nardi, 2002; Nardi, 1996b, 1996a; Nardi & Kaptelinin, 2006). In educational contexts, it has been used to analyze student participation patterns around virtual environments designed to develop students' scientific knowledge Barab et al. (2002). Cash et al. (2015) used activity theory's three-level hierarchy of activity to develop a multi-scale instrument to explain and describe the design process. Detlor, Hupfer, and Smith (2016) used activity theory to research a digital storytelling initiative implemented by two Canadian libraries. Activity theory is a flexible analytical framework that is used to analyze the full context of activity across time.

Three main sections comprise the remainder of this chapter. The first is a review of the creativity literature from a design perspective. The second section reviews the design literature, with an emphasis on design thinking and design as education. The third section reviews the activity theory literature with an emphasis on educational research and formative interventions. This review concludes with a summary of the key terms identified in the creativity and design literature that served as candidates for inclusion in the coding scheme used for this study (Appendix A.)

Creativity

This section of the literature review will identify aspects of creativity that are germane to design and design ability. These include (a) personal characteristics and attitudes that influence creativity, (b) different models of the creative process (c) environmental factors that influence creativity, (d) creative product design, (e) organizational creativity, (f) divergent thinking, (g) convergent thinking, (h) problem finding, and (i) tolerance of ambiguity.

Categories of creativity research. Researchers study creativity from multiple perspectives, and for this reason, a multifaceted approach to creativity is valuable (Albert & Runco, 2010; Kozbelt et al., 2010; Runco, 2004). Csikszentmihalyi (1988) suggested that a systems approach involving social institutions, cultural domains, and individuals was necessary:

> It [creativity] is the product of three main shaping forces: a set of social institutions, or *field*, that selects from the variations produced by individuals those that are worth preserving; a stable cultural *domain* that will preserve and transmit the selected new ideas or forms to the following generations; and finally the *individual*, who brings about some change in the domain, a change that the field, will consider to be creative.

Runco's (2007) began with an emphasis on complexity and suggested "An eclectic approach is necessary" (p. x) for the study of creativity. Hennessey and Amabile (2009) recommended using a systems perspective: "What we need now are all-encompassing systems theories of creativity designed to tie together and make sense of the diversity of perspectives found in the literature—from the innermost neurological level to the outermost cultural level" (p. 590). A similar conclusion was reached in the design thinking literature when Cross (2015) observed:

> The use of a variety of research methods has been required because to understand design ability it is necessary to approach it slightly obliquely. Like all kinds of sophisticated cognitive abilities, it is impossible to approach it directly, or bluntly (Cross, 2015, p. 6).

To deal with the considerable breadth and depth of creativity studies, the four *strands* of creativity proposed by Rhodes (1961) remain as useful tools for the analysis of creative studies and their findings. This organizational scheme will enable a systems perspective that also respects the eclecticism of creativity literature. These strands are known as the "four P's of creativity, i.e., (1) persons, (2) process, (3) press, and (4) products" (Rhodes, 1961, p. 307). Simonton and Runco suggested two additional categories of persuasion and potential, respectively. Since persuasive individuals often influence a domain, Simonton suggested this category of study. Since there is a difference between assessing either creative performance or creative potential, Runco suggested potential as a category of study.

The traditional categories of creativity research provide an organizational scheme for this review. Creativity is a dynamic phenomenon, and when subdivided into categories, it is essential to recognize their interrelatedness: "Each strand has a unique identity academically, but only in unity do the four strands operate functionally" (Rhodes, 1961, p. 306). What follows is a humble survey of literature across the categories that will look at various qualities, behaviors, and attributes that influence the development of creative potentials in people. This section concludes with a summary of ways these factors relate to student designers and design thinking.

Persons. The persons strand includes research into personal characteristics (Runco, 2004) which include social, cognitive, motivational, and affective dimensions of creative behavior. As for non-cognitive personal characteristics, a commonly used model for attempts to predict creative potential via personality traits is the *Five-Factor Model*. The Five-Factor model is not just used to explore creativity—psychology research uses this personality model in many ways. For example, Deming (2017), working from an economic perspective, used the “Big 5 personality inventory” (p. 1618) to support claims that social skills are increasingly crucial for high paying jobs in the labor market.

According to Digman (1990) and Goldberg's (1993) reviews, this model evolved from Fiske's (1949) collaboration with Veterans Affairs to select participants for psychological training programs and particularly Tupes and Christal's (1961) subsequent work with the United States Air Force to predict officer effectiveness. These researchers pioneered the application of factor analysis to language describing human personality traits and consolidated the descriptors to originate the Five-Factor model. Today, *Neuroticism*, *extraversion*, *openness*, *agreeableness*, and *conscientiousness* comprise the personality dimensions of the Five-Factor Model.

Creativity researchers have employed it to research the link between personality and creativity. For example, Feist (1998) conducted a quantitative meta-analysis by integrating the literature along the lines of personality and creative achievement and then by mapping those traits onto the five factors. Cohen’s d was used to calculate effect sizes for correlations of means across the five personality dimensions when mapped across three groups of people: scientists versus nonscientists, more creative versus less creative scientists, and artists versus non-artists. An emerging picture of the creative personality resulted from this work: “Creative people are more autonomous, dominant, hostile, and impulsive. Out of these, the largest effect sizes are on openness, conscientiousness, self-acceptance, hostility, and impulsivity" (Feist, 1998, p. 299). Feist's work represents an early and well-regarded effort to use a quantitative meta-analysis of the literature to construct a picture of creative personality types.

The study's findings about openness and creativity are echoed by research into the design thinking traits of individuals (Blizzard & Klotz, 2012; Blizzard et al., 2015; Cross, 1999; Dorst, 2011; Royalty et al., 2014; Thienen, Royalty, & Meinel, 2017). The positive correlation between autonomy and creativity shown by Feist (1998) also shows up in the literature describing project-based learning environments (Condliffe, 2016; Thomas, 2000).

At times, misconceptions about *who* is creative interfere with efforts to develop creative potentials within students (Bandura, 1997; Beghetto, 2006). Harrington (1975) correlated results from a personality instrument and divergent thinking tests and found that simply asking participants to "be creative" increased demonstrations of divergent thinking ability. He also found that underperforming participants also "lacked confidence in their intellectual and imaginative abilities" (p. 450) and conjectured their underperformance may have been "due to cognitively debilitating anxiety engendered by the ego-involving properties" and the instructions they received when performing the divergent thinking task. The overall findings suggested explicit instructions to be creative increased creative behavior, but interestingly, it was also possible the direct language such as "The following is a test of your ability to think creatively about…" (p. 438) inhibited creative behavior for those that lacked confidence in their abilities. Richards (2010) introduced the construct of *everyday creativity* "…as universal and central to human survival, and to the development of self and culture…" (p. 194). This construct supported the idea that everyone is creative and encouraged efforts to develop creative potential—especially for those holding the misconception that creativity is somehow beyond their abilities.

Taylor's (1960) hierarchical model along with Kaufman and Beghetto's (2009) *Four C Model* refined ideas about who (and what) is creative by using classification schemes elaborating various levels of the creative magnitude observed in creative people. The Four C Model included four categories of creativity. *Big-C* creativity involved "…clear-cut, eminent creative contributions" (p. 2) and a high degree of world renown across historical periods. *Little-c* creativity involved "everyday activities" (p. 2) of non-experts and laypeople and was especially useful for addressing misconceptions that limit creativity to the realm of genius. *Mini-c* creativity involved "…intrapersonal insights and interpretations, which often live only within the person who created them," (p. 4) and was intended to highlight the importance of unexpressed insights people have when learning new things. "Moreover, these 'beginner's mind' aspects of creativity (e.g., openness to new experiences, active observation, and willingness to be surprised and explore the unknown) seem to be characteristic of all creators (Richards, 2007)" (p. 4).

Pro-c creativity involved professional expertise where "Anyone who attains professional-level expertise in any creative area is likely to have attained Pro-c status" (p. 5). The Pro-c category was for those who attained Little-c status but not yet Big-C status. For example, student designers might set realistic goals to attain Pro-c status through sustained practice marked by successes in their related fields. The clarification might curb unrealistic and possibly demotivating student expectations of becoming expert designers as the result of attending a workshop or completing a course in design thinking.

Personality traits associated with creative behaviors and personally held beliefs about who is creative are likely to influence how design thinking develops for student designers. In turn, this understanding could inform the design of the learning environment to facilitate the creative design process.

Process. For Rhodes (1961), the creative strand of process "…applies to motivation, perception, learning, thinking, and communicating" (p. 308). The creativity literature deals with the analysis of the creative process in two general ways: stage theories of process and componential models of the process. Wallas (1926) used four stages to describe the creative process within the broader categories of conscious and voluntary effort. The four stages are as follows: 1) *preparation*, 2) *incubation*, 3) *illumination*, and 4) *verification*. Wallas theorized this model in response to the question: “I shall ask at what stages in that thought-process the thinker should bring the conscious and the voluntary effort of his art to bear” (p. 37).

The first three stages of this process model came from German physiologist and physicist Hermann Helmholtz’s response to questions about “…the way in which his most important new thoughts had come to him” (Wallas, 1926, p. 37). To these, Wallas added the fourth stage of verification for which he credited French mathematician Henri Poincare as inspiration. The model is represented with Figure 2.

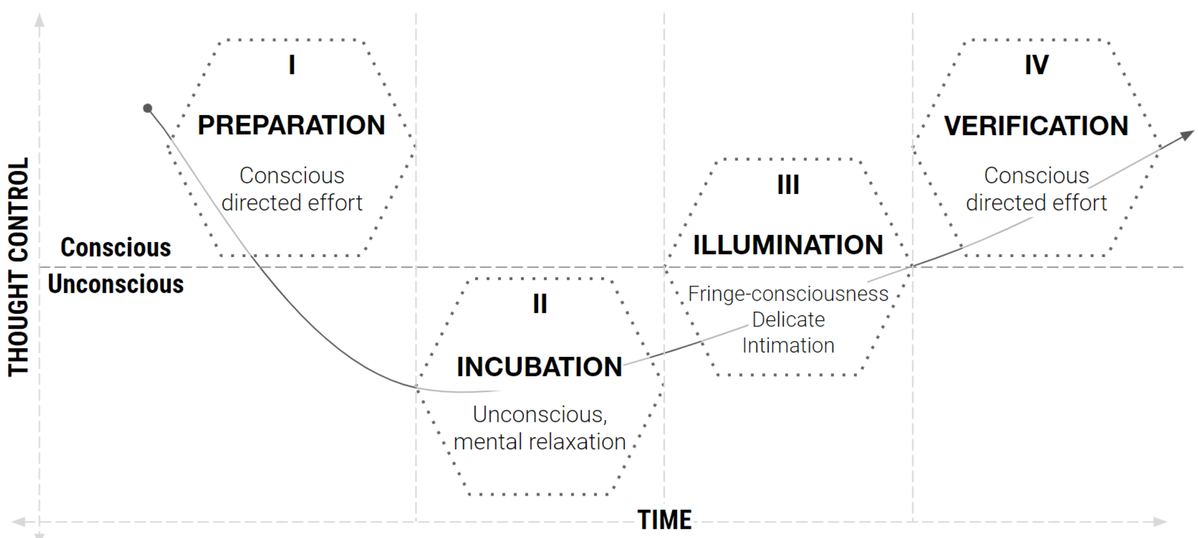

Figure 2. The art of thought as regulatory stages of control and the interplay of the conscious and unconscious thought process. Adapted from "The Art of Thought." by G. Wallas, 1926, Solis Press, pp. 37-55.

According to Lubart (2001), the preparation phase involved a conscious determination of the problem while drawing from personal experience and knowledge of the problem area. The next stage, incubation, was an unconscious stage of the creative process. During incubation, conscious attention to the problem receded while unconscious thought processes formed idea combinations and associations related to the problem. The third stage, illumination, occurred when potentially valuable ideas emerged into conscious thought.

A feeling of intuition often preceded moments of illumination and insight into the problem. The moment of illumination is popularly described in terms of a light suddenly flashing to life, but Wallas' meaning for illumination was more nuanced and delicate than the common lightbulb metaphor. Wallas (1926) referred to these feelings as delicate "intimations" occurring at the "fringe" of consciousness (Lubart, 2001, p. 296; Wallas, pp. 47-49). Wallas probably borrowed the term "fringe" from James (1890), who used it to describe aspects of consciousness that directly relate to that state between unconscious and conscious thought: "Let us use the words *psychic overtone*, *suffusion*, or *fringe*, to designate the influence of a faint brain-process upon our thought, as it makes it aware of relations and object but dimly perceived" (p. 258).

The incubation stage of the creative process is of great interest to researchers. Torrance (1979) developed an instructional method to support creativity through incubation, which is still being used today (Hines, Catalana, & Anderson, 2019). Research from cognitive science suggests incubation during sleep (Cai, Mednick, Harrison, Kanady, & Mednick, 2009; Lewis, Knoblich, & Poe, 2018) and mind wandering (Baird et al., 2012) improves creativity. The idea of better ideas due to sleep is not new as many people can intuit, and evidence of it can be traced to the writings of Henry VIII, although it is reasonable to assume the phenomenon goes back much further than that. "The King would not conclude with him tonight, but says that he will sleep and dream on the matter, and give him an answer in the morning" (Brewer, 1519). Wallas' early theorization of the incubation stage as an unconscious stage of the creative process aligns with Dijksterhuis and Nordgren's (2006) theory of unconscious thought. A practical implication here is that the development of creative ability is more likely to happen over longer than shorter periods. That is, an afternoon workshop on some form of creativity is not as likely to facilitate the development of creative potential as is spending a semester's worth of time on the effort. If the workshop did lead to the development of creative potential, it seems most likely due to the individuals' subsequent application of new knowledge across an extended period.

The term for the fourth stage was verification and closely resembled the first stage of preparation in that both stages involved fully conscious efforts of logical reasoning. This conscious stage of the model involved "…evaluation, refining, and developing one's idea" (Lubart, 2001, p. 296). Wallas' stage model accounted for the co-occurrence of stages, allowing for a return to the incubation phase should, for example, the verification phase led to a realization that the solution was insufficient. Dewey's (1926) review of the Wallas model emphasized the role of free play in the creative process:

> For American students, the emphasis upon the need of leisurely incubation, of allowing the mind free play without too conscious painful control, of adventuring in that border-ground just this side of mere fancy where most original ideas are born, is of especial value. (p. 119)

The idea of the "fringe" consciousness and unconsciousness as a source of information is old and predates Wallas' emphasis of it. In his recounting of Robert Lawler's research into indigenous aboriginal cultures of Australia, Abram (1997) describes the meaning Aboriginal Australians ascribe to perception and various atmospheric phenomena such as lightning, birds, and rainbows.

> Birds, who wing their way through the invisible, are often experienced as messengers of the unconscious, while the rainbow (the Rainbow Snake, who arcs upward across the sky and then dives back into the earth) is felt to personify all the most implacable, dangerous, and yet life-giving forces in the land. For the rainbow is perceived as the very *edge* of the Dreaming, as that place where the invisible, unconscious potentials begin to become visible. (Abram, 1997, p. 227)

Humans seem to intuit the connection between ideas and the unconscious. The ability to *recognize* the affordances of the phenomenon, however, may depend upon pre-existing knowledge.

In his discussion of the theory of information pickup and the concept of the perceptual system, Gibson (1979), distinguished between a *perceptual system* and a *special sense*, "A system has organs, whereas a sense has receptors. A system can orient, explore, investigate, adjust, optimize, resonate, extract, and come to an equilibrium, whereas a sense cannot" (p. 234). Perceptual systems involved continuous loops of incoming and outgoing nerve impulses. Description of a special sense as a "… a bank of receptors or receptive units that are connected with a so-called projection center in the brain" (p. 234) entailed the stimulation of inputs, whereas the perceptual system related to the "qualities of things in the world, especially their affordance" (p. 235). This distinction implied a limitation and variability between sensory input and perceptual awareness and the necessity of interpretation of sensory input— "sensations provide clues or cues for perception of the world" (p. 235).

So, in order to understand sensory input, a person must have a world view that can make sense of that particular sensory input. "But it seems to me that all such arguments come down to this: we can perceive the world only if we already know what there is to be perceived" (p. 235). So, the meaning ascribed to ideas that arise from the unconscious incubation stage during the transition of Wallas' illumination stage, may much depend upon what a learner is prepared to recognize.

The interplay between knowledge and perception implies the dialectical nature of developmental processes and how pre-existing knowledge—learned information—shapes the ability to make new discriminations and connections. The development of perception might be analogous to the development of expertise in a given domain of professional practice, such as design. In other words, design intuition may improve with practice and experience. From

Aboriginal Australians to professional engineers, the ability to assign meaning to the unconscious, percolating thoughts depends on the variety of pre-existing knowledge one has accumulated through experience and can bring to the act of perception.

This stage model of the creative process from 1926 has yet to become obsolete, but research has since produced more sophisticated theorizations of the creative process. For example, Basadur, Runco, and Vega (2000) incorporated the creative thinking subprocesses of divergent (*ideation*) thinking and convergent (*evaluation*) thinking across the eight subcomponents of their four-stage creative process model (i.e., the *Simplex Creative Process*) as reprinted from the original text and shown in Figure 3.

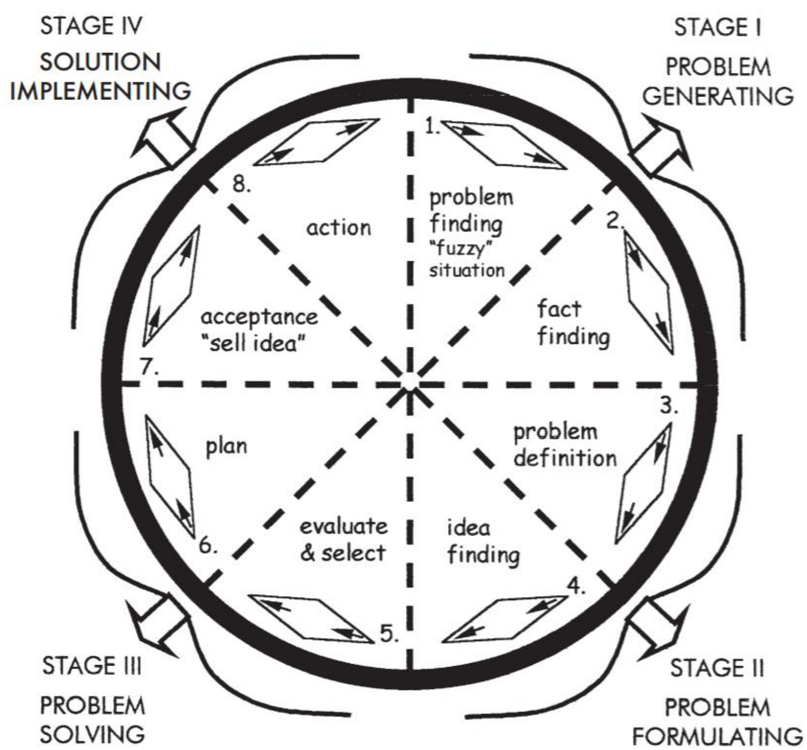

Figure 3. The Simplex Creative Process as a Whole. From "Understanding How Creative Thinking Skills, Attitudes and Behaviors Work Together: A Causal Process Model." by M.

Basadur, M. A, Runco, and L. A.Vega, 2000, The Journal of Creative Behavior, 34, p. 80.

The Simplex Creative Process was used to investigate how creative thinking skills, attitudes, and behaviors interrelated when managers learned and applied this model. Findings suggested that managers who valued deferring judgment demonstrated significant improvements in divergent and convergent thinking across the eight subcomponent skills of the Simplex process model. Figure 3 shows some of the many new constructs theorized by creativity research. Divergent and convergent thought processes occurred in each of the eight subprocesses. Problem finding occurred within and across the problem generating and formulating stages one and two. The seventh subcomponent of acceptance emphasized the rhetorical act of persuasion as a selling of the creative idea.

Even as models of the creative process have grown in sophistication over time, Wallas's classic stages of control have remained useful to creativity researchers (Lubart, 2001; Runco, 2004). The longstanding relevance of Wallas's stage model of the creative process could explain why most students of creativity are familiar with the stages of preparation, incubation, illumination, and verification. This persistence may also explain why very similar stages characterize some models of design thinking, which will be discussed later in this chapter.

These two models are by no means all the creativity literature has to say about the creative process. Howard, Culley, and Dekoninck (2008) reviewed literature from the areas of engineering design and cognitive psychology and identified 42 different process models. Still, the two models selected here can provide insight into the design process will serve as frames of reference when reviewing some models of the design thinking process. As a pair, they represent a longstanding yet straightforward initial conception of the creative process in the case of Wallas and the more sophisticated and modern conception of the process represented in the case of Basadur et al. (2000).

Using these two models as points along a continuum of the development of psychological constructs related to creativity is a way of showing its historical range development. Moreover, for this study, emphasis will be given to the processes discovered within student designers work as contextualized by activity theory. Also, the emphasis Wallas placed on the unconscious mind seems to have stood the test of time, and yet many textbook accounts of his theorization of the creative process seem to gloss over the fact that he was interested in the conscious vs. unconscious nature of the creative process.

Exactly how the unconscious mind affects ideation remains unknown, but anecdotal and scientific evidence continues to mount (Bargh & Morsella, 2008; Bargh, Schwader, Hailey, Dyer, & Boothby, 2012). There is a distinction between "quick" decision-making and "slow" decision making (Kahneman, 2013) that becomes a factor when considering the development of higher intellectual processes involving decision-making, like design and design thinking.

It is probably wise to spend a relaxed period away from the problem as a factor when assessing the quality of design decisions. Moreover, this has methodological implications for the study of design, which will be attended to in the final section of this chapter and will involve why sustained durations are essential for researching the development of thought processes. Descriptions of the creative process typically involve iteration, and descriptions of design thinking most always have an explicitly iterative component (Clinton & Hokanson, 2012; Hokanson, 2018; Sawyer, 2006).

Press. Unlike the rest of these alliterative terms used to categorize creative research, the meaning of the term press is not apparent and is the least intuitive. A parenthetical qualifier of "environment" often accompanies the term "press," which can amplify confusion around the intended meaning. For Rhodes (1961), who appropriated the term from Murray (1938), press

"…refers to the relationship between human beings and the environment…studies of press attempt to measure congruence and dissonance in a person's ecology" (Rhodes, 1961, p. 308). The ideas of pressure and how environmental pressures (both physical and social) can shape human activity may be helpful metaphors here. The term refers to "pressures on creativity" (Runco, 2004, p. 660).

This strand of creativity studies relates to the interaction of individuals and their environments. Murray distinguished between alpha and beta pressures where alpha pressures were objective instances of press and beta pressures were the individual's interpretations of press—even subjectivity qualified as an environmental dimension. When individual subjective experience is an additional component of press, environmental dimensions of creativity multiply accordingly.

Runco (2004) identified research topics within this strand including "…situational influences on creativity such as freedom, autonomy, good role models and resources (including time), encouragement specifically for creativity, freedom from criticism…" (p. 662) and organizational cultures that encourage innovation while not stigmatizing failures. Davis (1999) defined barriers to creativity and creative attitudes. Barriers were either external or internal blocks to creativity. Blocks were learned attitudes and behaviors resulting from interactions with others, including parents, teachers, business environments, or culture in general. Creative attitudes were linked to personality and either enhanced or blocked the development of creative potential.

Educators can impact the student's environment through their attitudes toward creativity. Davis used the term *squelchers* for negative speech that inhibited creativity with examples including "We've always done it this way!", "Be practical!" "Too risky!" and "It will never work!" The language used by teachers can be used to model positive, creative attitudes or to squelch creativity. "The contrast between creative and uncreative people lies more in barriers and uncreative attitudes than in differences in intelligence or thinking styles" (p. 165). For Davis, attitude is the most important contextual factor for the development of students' creative potentials.

Research concerning professional, organizational, and learning contexts has produced similar findings regarding creativity in the workplace. Amabile's (1996, 1998) research suggested business cultures and practices were instrumental in either supporting or killing creativity at work. Employee's *expertise*, *creative thinking skills*, and *motivation* were components that modeled creativity in the workplace and were influenced by appropriate levels of challenge, autonomy, resources in combination with the attitudes and values at work across managerial and organizational levels.

Other research has suggested the tone of the environment influences if creative behaviors is expressed or not (Cramond, 2005; Rogers, 1954; Runco, 2007a; Schein, 1999; Torrance, 1965). Rogers' (1954) experience as a psychotherapist led him to suggest "conditions of psychological safety and freedom" (pp. 256-257) were important facilitators of creativity. These conditions were achieved through the factors of attitudes, evaluation, empathy, and "freedom of symbolic expression" (p. 258). Facilitators (e.g., teachers, managers, coaches) of creativity needed to "accept the individual as of unconditional worth" (p. 257). This attitude showed individuals that their ideas are valid, and it is okay to have them. External evaluation and judgment should not include value statements. That is, it is okay to express dislike of an idea, but not okay to declare an idea is either bad or good. In the first case, the reaction is simply someone else's opinion and allows the other person to hold onto the validity of their idea. The second case is an evaluation, not a reaction. The idea is evaluated as wrong, negates the ability of the individual to assess the validity of his or her ideas, and inhibits creative behavior.

Rogers (1954) suggested empathy provided "the ultimate in psychological safety" (p. 258). Communicating empathy expanded the generic acceptance of all individuals to include showing an understanding of the individual. Empathy involved the abilities to relate with, understand, and accept individuals. Freedom of *symbolic* expression differentiated between all possible behaviors and the symbolic expression of behaviors. While some behaviors are clearly unacceptable, Rogers (1954) suggested the “permission to be *free*” (p. 258) linked with personal responsibility. The freedom to symbolically express any idea, even socially unacceptable ones, fostered “openness, and the playful and spontaneous juggling of percepts, concepts, and meanings, which is a part of creativity” (p. 258). These were the external conditions Rogers (1954) proposed to encourage the inner conditions of creativity, which “cannot be forced, but must be permitted to emerge” (p. 256).

Torrance (1965) proposed creative behavior was encouraged by an optimal balance between stimulation and quiet reflection. That is, overstimulation was as much a barrier to creativity as was under-stimulation. This idea recalls Wallas' (1926) emphasis on the interplay of conscious and unconscious thought within the creative process. Although quiet reflection is not the same state as unconscious thought, it is neither entirely dissimilar. Another connection is found in Papert’s discussion of learning and problem solving when he observes, “spending relaxed time with a problem leads to getting to know it, and through this, to improving one’s ability to deal with other problems like it” (p. 12). An educational system that ignores these ideas will probably discourage the development of creative ability and perhaps learning in general, as is suggested by Elkind's (1981) critique, “The factory model of education hurries children because it ignores individual differences in mental abilities and learning rates and learning styles” (p. 50). In situations where educational practices are rushed and pressurized, it is probably important to build relaxed time into course designs, especially when encouraging creativity.

Within the press strand of creativity research, the physical environment is also of research interest. McCoy and Evans (2002) conducted studies to investigate the role of specific interior design elements and their relationship to creative potential. In the first study, researchers conducted a review of the literature to identify seven theoretical dimensions to serve as variables for physical environments. Next, the researchers reduced a pool of 1200 photographs to 75 using themselves and an independent group of raters to place the images across the seven theoretical interior design variables according to their means and standard deviations.

A *Q* sort method involved fifteen identical decks of the shuffled images given to 60 participants who were asked to sort the images into a normal distribution of 11 piles ranging from environments they would either most or least be likely to choose. The *Q* sort addressed the question: "If you had a very special problem to solve and needed to generate a lot of new ideas, where would you most likely choose to go?" (p. 413). Stepwise regression analysis determined which design elements predicted creativity potential.

Results from this study suggested five environmental characteristics associated with high creative potential and three environmental characteristics associated with low creative potential. These findings are displayed below in Table 3, reprinted from the original article.

Table 3
Environmental Characteristics of Physical Settings That Influence Creativity Performance

High Creativity Potential	Low Creativity Potential
Spatial complexity	Cool color temperature
Visually detailed	No view
View of natural environment	Manufactured/composite material
Use of natural material	
Sociopetal design	

Note: From "The Potential Role of The Physical Environment in Fostering Creativity." By J. M. McCoy, and G. W. Evans, 2002, Creativity Research Journal, 14, p. 418. Copyright 2002 by Taylor & Francis. Reprinted with permission.

Participants seemed to care neither about the shape or size of the space but did show preference for spaces that were spatially and visually complex. Neither quantity nor quality of light in a space significantly mattered to the participants. Both furniture and visual detail were highly correlated with creative potential, especially when the furniture afforded a high degree of social interaction. Human-made materials had a strong negative correlation with creative potential whereas natural materials such as wood or stone resulted in high correlations with creative potential.

Moreover, higher amounts of texture and more textures indicated higher perceived creative potential. Cool color temperatures negatively correlated with creative potential while glass and views correlated with high creative potential. These results might inform the design of studio learning spaces. The use of images with *Q* methodology is a research method that could be adapted for other research contexts, especially when written language is a barrier or otherwise inappropriate to the research goals.

Thoring, Desmet, and Badke-Schaub (2018) began research to create a typology of creative spaces with a literature review around search terms creative learning, work, and office spaces. The analysis yielded few satisfactory results, and so they began development of their typology via a qualitative approach involving "cultural probes"—boxes containing a diary with prompts, several floor plans, a single-use camera. Nine design students received the probes and had two weeks for completion. Researchers then analyzed the data via open and axial coding methods and identified five types and five qualities of creative spaces as reproduced in Table 4 below.

Table 4

Types and Qualities of Creative Spaces

Space type	Spatial quality
Personal space	Knowledge processor
Collaboration space	Indicator of culture
Presentation space	Process enabler
Making space	Social dimension
Intermission space	Source of stimulation

Note: From "Creative Environments for Design Education and Practice: A Typology of Creative Spaces." by K. Thoring, P. Desmet, and P. Badke-Schaub, 2018, Design Studies, 56, p. 73. Copyright 2018 by Elsevier. Reprinted with permission.

A second study was conducted to validate the typology and involved a focus group workshop consisting of nine non-student participants from various creative backgrounds. Participants were grouped in teams or two or three and asked to discuss the proposed typologies while a researcher observed and took notes. The data was found by the researchers to validate the five space types and spatial qualities identified in the initial study and discussion included the recommendation to use the identified typologies from this study to inform the design of virtual collaborative spaces in virtual worlds.

The social dimension and the individual's relatedness to it are especially relevant to research involving how design thinking develops for student designers. The architecture of learning spaces and the meanings student designers assign to them might be used to inform the design of learning activities for courses involving design thinking.

Products. Creative ideas are often expressed in tangible form by artifacts of some kind, or products. "When an idea becomes embodies into tangible form it is called a product…products are artifacts of thoughts" (Rhodes, 1961, p. 309). While much of the research around creative products involves visible artifacts, the product category also includes intangibles like scents, tastes, sounds, visuals, and ideas. Rhodes efforts to "classify products according to the scope of newness" (p. 309) led him to categorize ideas, specifically theory, in a higher order than inventions. His beliefs held that theories are of a higher order than inventions because theories held the potential for germinating thousands of inventions whereas inventions potentiated "…numerous innovations or new twists in design or structure are suggested by the users…[and his classification system would]…place emphasis on higher mental processes rather than on dazzling objects" (p. 309). Seymour Papert, regarded as the "father of constructionism," expressed a similar conviction when addressing the role of technology in education: "But the revolution I envision is of ideas, not of technology" (Papert, 1993, p. 64).

Norman and Verganti (2014) distinguished inventions as either incremental or radical innovations. Incremental innovations were “improvements within a given frame of solutions (i.e., 'doing better what we already do')” (p. 82) and radical innovations were “a change of frame (i.e., 'doing what we did not do before')” (p. 82). Incremental innovations occurred along a continuous arc of development and referenced established norms whereas radical innovations represented unique artifacts and a sharp break from accepted practice.

A classification system, or rubric, for creative artifacts, is integral to understanding how they came to be. Rhodes (1961) used archeology as a metaphor, connecting the archeologists' use of artifacts as a way of reconstructing past ways of life, to the psychologists' use of inventions as a method for reconstructing ways of inventing. Rhodes connected all strands of creativity studies to the products of creativity: “Objective investigation into the nature of the creative process can proceed in only one direction, i.e., from product to person and thence to process and to press” (p. 309). The implication is that limiting creative studies to product is problematic because the context of the product’s creation is lost—making it impossible to determine if the product was creative, or not.

The assessment of an artifact’s creativity depends on understanding the context of the artifact’s creation. Runco (2004) added that “An individual can be productive without being original, and originality is the most widely acknowledged requisite for creativity. In methodological terms, productivity and creativity are correlated but not synonymous” (p. 663). It is the context which addresses questions regarding the originality and usefulness of the produced artifact.

Csikszentmihalyi and Getzels (1971) used multiple methods involving an initial operationalization of variables, participant observation, and product evaluation to investigate the “problem-formulation” stage of the creative process. The research question for this study was: “Is discovery-oriented behavior in a real-life situation involving creative production related to the assessed creativity of the product" (p. 48). Thirty-one students in a high school art class were separately asked to pick from 27 available objects and create an arrangement of objects they would like to draw. There was no time limit. Researchers photographed and observed participants working on the task and interviewed participants when the tasks were completed.

Five well-known art critics and artists judged the student drawings along the three dimensions of craftsmanship, originality, and aesthetic value using a 1-9 point scale. Observational data to measure *discovery orientation* included the following variables:

1. number of objects manipulated;
2. uniqueness of objects chosen;
3. discovery-oriented behavior during selection and arrangement (operationalized according the level of evaluation students were observed to give each selected object);
4. total problem-formulation score, which was calculated based on how much above the median students scored on the preceding three variables.

Another set of observations measured *discovery at the stage of problem solution* and included: (a) openness to problem structure (calculated based on how long it took students to create the arrangement of objects they were to draw); (b) discovery-oriented behavior while drawing (calculated based on to what degree students paused or rearranged objects as they completed their drawings); and (c) changes in problem structure and content (calculated based on the degree to which the student drawings showed transformations of the original arrangements). This effort to make the artistic process observable contextualized the produced artifacts with observed behaviors and product evaluation. Correlations between the observed behaviors and the product evaluations suggested a positive relationship between discovery-oriented behavior during the formulation of the problem and the construct of originality as determined by the judges.

Taking care to initially frame the problem correlated with original products. Of methodological interest is that the researchers specified the task for the students. Being given specific directives must influence participant behaviors and outcomes. Also, the use of expert judges to rate creative products continued to be a highly regarded method for the assessment of creativity (Amabile, 1982) and since that time has morphed into the phenomenon of crowdfunding as evidenced by social-media mechanisms such as Kickstarter (Mollick & Nanda, 2016).

Amabile (1982) and Amabile and Pillemer (2012) connected the social psychology of creativity with business practices and developed a method to assess the creativity of products in the workplace. Amabile's (1982) consensual assessment technique "…is rooted in a consensual operational definition of creativity: a product is creative to the extent that expert raters independently agree upon this judgment" (Amabile & Pillemer, 2012, p. 6). The consensual assessment technique integrates social validation into the assessment of creativity by way of judges, instead of surveys, to assess product creativity.

To summarize the categories of creativity research of persons, process, press, and products and how they might relate to design thinking. Knowledge of the kinds of personality and cognitive qualities associated with creative behaviors can help researchers identify creative design behaviors in students, as has been attempted with the survey construction of Blizzard et. al. Also, knowledge of the ranges of creativity found in individuals can help to correct misconceptions students might have about their creative potentials as a first step to developing creative potentials might be a simple understanding that it is, in fact, there.

An awareness of different theorizations of the creative process can inform the use of design thinking models and the expectations placed on them. A practical value of the design thinking models seems to be their tidy combinations of theory and practice which emphasize creative designer behaviors involving the determination of the problem (preparation).

Determining the problem, or preparation, relates to designers checking to be sure they are solving the right problem and their ability to reframe the problem and solution spaces in order to achieve the kind of value they are trying to achieve as designers. Unconscious problem-solving (incubation) may be present in different degrees during the design process and precedes the “aha!” moment (illumination). Unconscious problem-solving, or incubation, may be supported by the ability to tolerate the ambiguity inherent but not limited to design problems. Tolerance of ambiguity can also be related to the idea of resistance to premature closure, where one way of measuring this creative behavior is the Torrance figural test.

Critically examining ideas to determine their relevance to the problem (verification) could manifest within the design process as prototype testing and making design changes based on peer or instructor feedback. More recent stage models of creativity emphasize the importance of divergent and convergent thinking process for creative behaviors. The ability to divergently ideate can relate to design practices like problem finding or openness to experience and new ideas. It can also relate to an attitude of experimentation, especially the deductive thinking process associated with experimentation—testing the hypothesis. The ability to convergently evaluate can relate to selecting from a divergent pool of ideas and making design decisions such as problem finding.

For press, or the environment, the interaction of individuals with their environments was highlighted. Individuals’ perception of their environments has just as much effect on creativity as the actual physical environment. Environmental barriers to creativity included prior learning as well as teacher attitudes. It was suggested that barriers and negative attitudes about creativity distinguished creative people from non-creative people more so than either intelligence or cognitive abilities.

Squelchers, or expressed negative attitudes toward creativity, inhibit creativity. The design thinking literature emphasizes the constructs of self-efficacy, creative agency, and optimism (Blizzard et al., 2015; Royalty et al., 2014) as qualities seen in design thinkers. Also, the physical environment was discussed, and interior design attributes supporting attitudes toward creativity were reviewed and included visual complexity, natural materials, natural light, glass, and natural views.

Organizational creativity. Within the creativity literature, design thinking is categorized as a form of organizational creativity. Design thinking is a human-centric, flexible, lightweight, and highly adaptable intervention used in business and education which will be reviewed later in this chapter. Within the category of organizational creativity, design thinking is one of many forms of problem-solving strategies used to facilitate creativity and innovation (Kozbelt et al., 2010; Puccio & Cabra, 2010).

The field of organizational creativity has evolved to expand its scope from individuals to a more systems-oriented view—with an emphasis on leadership. Woodman, Sawyer, and Griffin (1993) defined organizational creativity as "the creation of a valuable, useful new product, service, idea, procedure, or process by individuals working together in a complex social system" (p. 293). Organizational creativity scholars Puccio & Cabra (2010) noted that the topic of leadership had garnered increasing attention in the field's body of research. Scholarship around the intersection of leadership, creativity, and innovation suggests that managers must value and integrate creativity into workplace culture in order for innovation to occur (Amabile, 1988; Amabile, Conti, Coon, Lazenby, & Herron, 1996; Amabile & Pratt, 2016). Amabile (1988) proposed a longstanding and highly cited model for creativity and innovation within organizations, the *componential model for organizational innovation*.

A closer look at this model and its recent update will provide an example of one manifestation of scholarship within the field of organizational creativity. This effort might also provoke ideas around the facilitation of design thinking and its methods in educational contexts.

The researchers developed the preliminary model for creativity and innovation in organizations by conducting interviews where participants were asked to talk about "… one event that exemplified high creativity, and one that exemplified low creativity" (Amabile, 1988, p. 124). Analysis of the interview data revealed the central phenomenon that "…individual creativity and organizational innovation are closely interlocked" (p. 125).

The resultant componential model for organizational creativity adhered to four essential criteria. Individuals were crucial to the process of the organizational innovation model. In turn, all aspects of the organization that influenced innovation were crucial to the model. Additionally, the major stages of the innovation process were a component of the model. Finally, organizational factors that influenced individual creativity were included in the componential model for organizational innovation. A simplified version of the model is displayed in Figure 4.

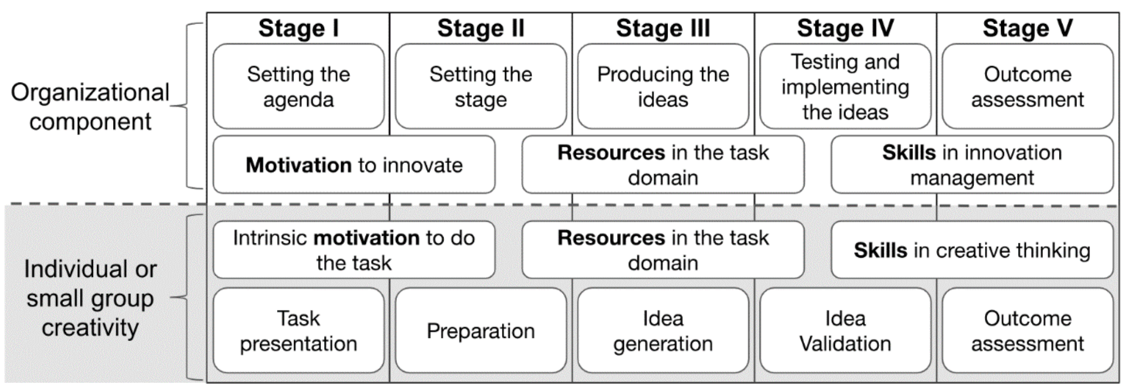

Figure 4. The componential model of organizational innovation. Adapted from "A Model of Creativity and Innovation in Organizations." by T. M. Amabile, 1988, Research in Organizational Behavior, 10, p. 152.

The model consisted of five stages for both the organization and individuals (or small groups). Three organizational components connected the individuals with the organization. These organizational components were: *motivation to innovate*, *resources in the task domain*, and *skills* *in innovation management*. The highest creativity for individuals and organizations occurred when the triad of motivation, resources, and skills (techniques) overlapped. The model's individual component contrasted task skills with creative skills and extrinsic motivation with intrinsic motivation, with emphasis on "…the way in which extrinsic constraints can undermine intrinsic motivation and creativity" (Amabile, 1988, p. 146).

There were three broad implications associated with this model. Hiring practices should involve finding employees with task domain skills, creativity domain skills, and intrinsic motivation. The two other implications of the componential model for organizational innovation involved sustaining employee intrinsic motivation: (a) identify and expand elements in the organization that facilitate creativity and (b) identify and eliminate elements in the organization that inhibit creativity.

Design thinking is one of several strategic approaches used in business and industry to improve organizational creativity (Kozbelt et al., 2010). Since then, Anderson, Potonik, and Zhou (2014) noted that the body of research surrounding this field had grown considerably and proposed "a guiding framework for future research comprising 11 major themes and 60 specific questions for future studies" (p. 1297). The researchers suggested a new definition highlighting the terms *creativity and innovation*:

> Creativity and innovation at work are the process, outcomes, and products of attempts to develop and introduce new and improved ways of doing things. The creativity stage of this process refers to idea generation, and innovation refers to the subsequent stage of implementing ideas toward better procedures, practices, or products. Creativity and innovation can occur at the level of the individual, work team, organization, or at more than one of these levels combined but will invariably result in identifiable benefits at one or more of these levels of analysis (Anderson et al., 2014, p. 1298).

This definition of organizational creativity recognizes the importance of both creativity and innovation. Organizational creativity is concerned with the combination of creativity and innovation to create something of value.

Haselwanter and Soila-Wadman (2016) suggested the use of design thinking to improve the organizational creativity of the Swedish trade union UNIONEN. The trade union aspired to innovate and implement creative business practices to improve membership numbers. The researchers followed a weekly artistic intervention process led by an artist for a trade union. The researchers encountered "…discontent and differences in ways of understanding business versus creative goals" (p. 33). Participants in the UNIONEN artistic workshops had difficulty with the intervention's lack of structure and resisted the intervention. The problem of managerial resistance to the adoption of creative practices in business is not new as noted by (Brown & Kuratko, 2015, pp. 147–148).

The researchers suggested educating the union management about design thinking methods would result in less resistance to artistic interventions. Design thinking could offer a clear description of design within business management—artistic interventions might meet with more acceptance if design thinking was first used to explain the creative process to the managers. The researchers concluded that education was a necessary first step in gaining traction at the managerial level with interventions concerning creativity and innovation.

Recommendations for reassessments of work, learning, and innovation within organizations and the redesign of workplace cultures to cultivate learning communities is not new (Brown & Duguid, 1991; Wenger, 1998). Brown and Duguid (1991) suggested organizations could more effectively innovate when organizational architectures facilitate workplace learning practices via a "...healthy autonomy of [learning] communities, while simultaneously building an interconnectedness through which to disseminate the results of separate communities' experiments. In some form or another the stories that support learning-in-working and innovation should be allowed to circulate" (p. 54).

For the UNIONON case, Haselwanter and Soila-Wadman (2016) recommended design thinking as a pedagogical tool to unify two groups of people within the organization—the ones who desired creativity training and the ones who did not.

Amabile and Pratt, (2016) used diary research to better understand how work environments could better facilitate creativity. Their work resulted in a revision of the dynamic componential model of creativity and found managers could facilitate creative work environments by (a) being motivated to innovate, (b) providing resources in the task domain, and (c) securing skills in innovation management. Table 5 is reprinted from the original article and displays elements of the work environment managers can mediate to influence creativity.

Table 5

Elements of the Work Environment for Creativity

Organizational innovation component	Creativity stimulant ("Catalyst")	Creativity obstacle ("Inhibitor")
Motivation to innovate	Clear organizational goals Value placed on innovation Support for reasoned risk-taking & exploration	Unclear/shifting organizational goals Disinterest in new undertakings Overemphasis on the status quo
Resources in the task domain	Sufficient resources Sufficient time, but not too much	Insufficient resources Insufficient or over-abundant time
Skills in innovation management	Clear project goals Autonomy in how to meet project goals Mechanisms for developing new ideas Participative decision-making Frequent, constructive feedback on new ideas Work assignments matched to skills & interests Equitable, generous reward & recognition for	

	creative efforts Collaboration & coordination between groups Help with the work* Learning from problems* Open idea flow*

Note: From "The Dynamic Componential Model of Creativity and Innovation in Organizations: Making Progress, Making Meaning." by T. M. Amabile, and M. G. Pratt, 2016, Research in Organizational Behavior, 36, p. 169. Copyright 2016 by Elsevier. Reprinted with permission.

Design thinking offers a unified, easy to understand structure lending itself to implementing many of these elements. Teachers can use their authority to facilitate creativity by modeling creative practices for students (Clinton & Hokanson, 2012; Collard & Looney, 2014; Runco, 2007a). Ideas like these from the organizational creativity literature can help educators manage creative learning experiences for students. Providing students a positive experience with strategies for organizational creativity, like design thinking, might yield future leaders who recognize, understand, and value creative practices in the workplace.

Divergent and convergent thinking. Hennessey and Amabile (2009) define divergent thinking as “spontaneous, free-flowing thinking with the goal of generating many different ideas in a short period” (p. 574) and convergent thinking as “more disciplined thinking, focused on narrowing possibilities to a workable solution” (p. 579). Guilford (1959) is known throughout the creativity literature for his work on “…development of a unified theory of human intellect, which organizes the known, unique or primary intellectual abilities into a single system called the ‘structure of intellect’” (p. 469). This three-dimensional factorial model was organized along three axes: *operations*, *products*, and *contents*. Divergent and convergent thinking were two of the five factors in the operations category. Divergent thinking was operationalized using the four variables of *originality*, *fluency*, *flexibility*, and *elaboration*. These variables were used to calculate divergent thinking scores using a variety of tests involving image manipulation, word associations, phrase completion, matching games, responses to stories—Guilford's prompts were highly innovative.

Originality is scored based upon the uniqueness of a response as compared to responses from other test takers. Fluency is simply the number of responses provided. Flexibility is concerned with the number of different categories seen within the responses. Elaboration is scored based upon the level of detail and depth of development of a response. These dimensions of divergent thinking can be predictive of creative potential. The alternate uses test involves asking participants to list all possible uses for an everyday object. The four dimensions described above are then used to analyze and score participant responses. Some creativity scholars expressed concerns in using fluency, the numerical quantity of responses to a prompt, to predict creative thinking potential. Quality is also a way of assessing creativity and "…creativity researchers ought to reconsider the value of subjective scoring of divergent thinking responses" (Silvia et al., 2008, p. 72). One example of this is the Consensual Assessment Technique (CAT) (Amabile, 1982) where a panel of judges is used to assess creativity.

Regardless of how divergent thinking is assessed, it is important not to equate divergent thinking with creativity because divergent thinking is just one subcomponent of the creative process. Both Guilford and Torrance advanced the theoretical construct of divergent thinking and the assessment of it. Tests of divergent thinking are only intended to measure creative potential. An alternative approach involves assessment of what the creative potential produced—a piece of art, a commercial product, a design idea or prototype, and so on. "Tests of divergent thinking have dominated the field of creativity assessment for several decades. This has created one problem, namely that occasionally they are regarded as tests of creativity. As noted, that is not a tenable view" (Runco & Acar, 2012). The ability to generate divergent ideas may at times correlate with creativity, especially when complemented by an ability to evaluate and converge on a selection.

There is consensus within the creativity literature that creative problem-solving involves a combination of divergent and convergent thinking (Hennessey & Amabile, 2009; Lubart, 2001; Mumford, Mobley, Uhlman, Reiter-Palmon, & Doares, 1991; Runco, 2007a). Cropley (2006) described convergent thinking as "…oriented toward deriving the single best (or correct) answer to a clearly defined question. It emphasizes speed, accuracy, logic, and the like and focuses on recognizing the familiar, reapplying set techniques, and accumulating information" (p. 391). Design decisions might be preceded by free-flowing imaginative, divergent thinking but at some point, something must be selected—a decision must occur.

The type of problem being addressed suggests which kind of creative subprocess (divergent or convergent thinking) might be invoked. A well-structured or tame problem might emphasize convergent thinking. For example, prompting a student to solve for x given the equation $3 + x = 7$ is a well-defined problem requiring very little if any creativity. An ill-structured or messy problem might emphasize divergent thinking—for example, the planning of an event for thousands of people. For the well-structured problem, all information required to solve it is provided whereas for the ill-structured problem much of the information required is missing. Ill-structured problems will require a combination of divergent and convergent thought and will require "…sequential or iterative decision-making processes" (Jonassen, 2012, p. 342).

While some creativity researchers may need to rebalance creativity assessments with more emphasis on convergent thinking, most school systems use assessments that focus on convergent thinking only. Runco (2004) noted, "…most tests given in the schools require primarily convergent thinking (there is only one correct or conventional answer) and relegate divergent thinking (where an individual can think about original options)" (p. 670). Table 6 below is reprinted from Cropley (2006) and used examples to compare divergent and convergent thinking processes.

Table 6

Comparison of Convergent and Divergent Thinking

Kind of Thinking	Convergent	Divergent
Typical processes	Being logical	Being unconventional
	Recognizing the unfamiliar	Seeing the known in a new light
	Combining what "belongs" together	Combining the disparate
	Homing in on the single best answer	Producing multiple answers
	Reapplying set techniques	Shifting perspective
	Preserving the already known	Transforming the known
	Achieving accuracy and correctness	Seeing new possibilities
	Playing it safe	Taking risks
	Sticking to a narrow range of obviously relevant information	Retrieving a broad range of existing knowledge
	Making associations from adjacent fields only	Associating ideas from remote fields
Typical results for the individual	Greater familiarity with what already exists	Alternative or multiple solutions
	Better grasp of the facts	Deviation from the usual
	A quick, "correct" answer	A surprising answer
	Development of a high level of skill	New lines of attack or ways of doing things
	Closure on an issue	Exciting or risky possibilities
	A feeling of security and safety	A feeling of uncertainty or excitement

Note: From "In Praise of Convergent Thinking." by A. Cropley, 2006, Creativity Research Journal, 18, p. 392. Copyright 2006 by Taylor & Francis. Reprinted with permission.

Basadur (1995) developed a three-stage model of creative problem solving where each stage included a two-step process analogous to divergent-convergent thinking: ideation-evaluation. The graphic of the model is reprinted from the original article and displayed in Figure 5.

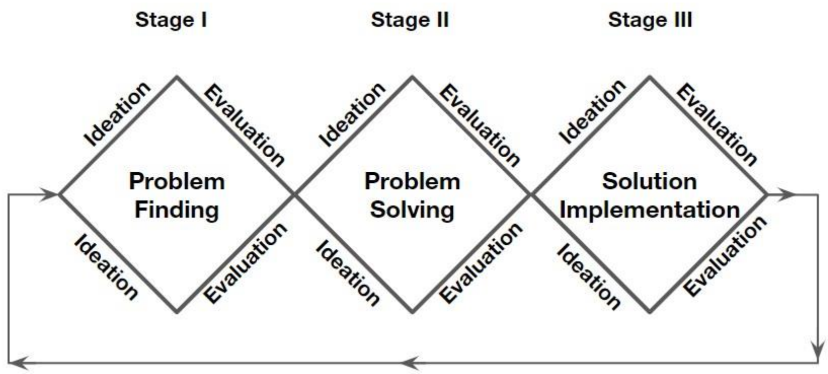

Figure 5. A complete creative problem-solving process emphasizing ideation-evaluation as a two-step process in each of three stages. Slightly adapted from "Optimal ideation-evaluation ratios." by M. Basadur, 1995, Creativity Research Journal, 8, p. 65. Copyright 1995 by Taylor & Francis. Reprinted with permission.

Basadur et al. (2000) found the quality of a solution was highly and positively correlated with the number of ideas generated suggesting that active divergence creates an ideational pool that in turn affords selection (convergent thinking) of the most optimal solution. Divergent thinking and convergent thinking were part of the overall process and nested within the three stages (problem finding, problem-solving, and solution implementation) of this creative process model.

The British Council offers a simple process model of the design process called the “double diamond model” which also includes problem finding and problem-solving stages, with the divergent-convergent thinking processes included with each stage (Design Council, 2019; Howard et al., 2008). The creative design process involves multiple iterations of thought involving both divergent and convergent thinking that are both influenced by contextual factors like subjectivity and the social environment.

Problem finding and tolerating ambiguity. There is a consensus that problem finding ability is a necessary first step in generating quality solutions. Runco observed, “…most people studying or experiencing problem finding believe that is more important than problem-solving skill" (Runco, 2007a, p. 16). Years ago, Mackworth's (1965) landmark article described scientific originality by distinguishing between problem finding and problem solving. He suggested problem finding was more cognitively demanding and "more important than problem solving" (p. 52). He observed that computers were adept with problem solving, poor with problem finding, and were "more successful at stimulating human intelligence than in replacing it [with] a more efficient problem-solving machine" (p. 56). Compared with problem-solving, problem-finding was rare in the scientific community, and yet it was the key ability needed to speculate, formulate, and test ideas. Mackworth (1965) quipped, "A superabundance of problem-solving techniques could cause a famine of ideas" (p. 52).

The Csikszentmihalyi and Getzels (1971) study outlined earlier was an early example of research using observation and analysis of student drawing to understand the problem finding part of the creative process, which was operationalized with terms like *concern for discovery*, *discovery orientation*, and *discovery at the stage of problem formulation*. These variables were found to correlate with the originality of drawings significantly. These ideas relate to the kinds of problems with which designers typically work, and Runco suggested the degree of problem finding existed along a continuum where on one end the problem is supplied (a well-structured problem), and on the other end, the problem is incomplete or unclear (and ill-defined problem).

Problem finding also relates to the skills predicted by Frey and Osborne (2017) to be resistant to computerization for the next decade or so— *perception and manipulation*, *creative intelligence*, and *social intelligence*. Computers are better at solving problems when parametric data is supplied but weak at discovery or finding problems. Newell and Simon's *General Problem Solver*, one of the earliest computer programs that applied means-ends analysis to support the decision-making process (Newell, Shaw, & Simon, 1959), was adept at solving well-specified problems but otherwise unsatisfactory.

The main limitation of the program was the need for the problem to be well-specified during the initial stage. Problem finding remains an elusive goal for artificial intelligence. Artificial intelligence excels at solving problems within specific contexts that humans define—for example, the context of playing an elaborate game like AlphaGo. Place the same computer in a different context, and it becomes clear that Simon's vision of a "general" problem solver has yet to materialize.

Designers, on the other hand, perceive and shape the world through their creative agency and within a variety of socio-cultural contexts. Within the field of instructional design it is typical, as specified by the ADDIE model of instructional design, for designers to first perform a front-end analysis of the site and context to determine problem characteristics before moving into the design, development, and implementation of the solution (Dick, Carey, & Carey, 2009). Good problem finding skills correlate with good solutions. Tukey (1962) reminded statisticians of the importance of facing uncertainty, "Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise" (pp. 13-14). As Norman (2013) observed, "A brilliant solution to the wrong problem can be worse than no solution at all: solve the correct problem" (p. 218). So, what makes a good problem finder?

Those who value deferring judgment tend to have high divergent and convergent thinking skills when problem-solving (M. Basadur, 1995; M. Basadur & Finkbeiner, 1985; M. Basadur et al., 2000). Deferring judgment involves the ability to tolerate ambiguity in the problem-solution space. The study of decision making and specifically of deferring judgment can be traced back to Adorno, Frenkel-Brunswick, Levinson, and Sanford's (1950) work to investigate the authoritarian syndrome. Subsequently, Rokeach (1960) explored the link between dogmatism and tolerance of ambiguity. Before this, Rokeach (1948) developed the 16-item *Rydell-Rosen Ambiguity Tolerance Scale* to investigate ethnocentrism. Macdonald (1970) revised the scale to 20-items, improved its reliability and validity, and formulated *Tolerance of ambiguity* as a construct. Tolerance of ambiguity also relates with openness, one of the “Big Five” personality traits (openness, conscientiousness, extraversion, agreeableness, and neuroticism) initiated by Tupes and Christal's (1961) work leading to the Five-Factor Model.

Zenasni et al.'s (2008) multivariate approach to the study of creativity suggested that “intellectual abilities, knowledge, cognitive style, personality traits, motivation, and a favorable environment are important factors for creativity” (p. 61). The authors used a divergent thinking task, a story-writing task, and self-report measures assessing Tolerance of ambiguity with 34 adolescent/parent pairs to investigate different facets of creativity. The divergent thinking tasks and story-writing tasks used ambiguous stimuli to prompt participant responses. The fluency and originality counts of list items were used to assess participant responses to the divergent thinking task. Three judges and an adjective checklist for creative behavior were used to assess the story-writing task. Two self-report measures were used to assess tolerance/intolerance of ambiguity. Another measure used 27 statements linked to ambiguous behavior and a seven-point Likert scale. An additional survey asked the participants to use a five-point Likert scale to rate 14 statement items related to ambiguous behavior.

Results supported the hypothesis that the more individuals tolerate ambiguity the more creative they tend to be and showed positive and significant correlations between individuals’ Tolerance of ambiguity with fluency and uniqueness of ideas. Although there was a significant and positive correlation between parents and their children’s creativity, there was no correlation with Tolerance of ambiguity. The difference in how parents and their children tolerated ambiguity makes sense when considering the Helson, Kwan, John, and Jones (2002) finding that the Big Five personality trait of openness negatively correlated with increases in lifespan.

Openness and a Tolerance of ambiguity most likely support creativity during the discovery and problem finding stages of the creative process and may help to describe the quality of curiosity in general. For designers engaged with ill-defined problems, a Tolerance of ambiguity might support persistence, resistance to premature closure, discovery orientations to problem finding, and the proclivity to play with problems, all of which appear to have a positive correlation with creativity.

Summary of creativity. The categories of persons, process, press, and products provided a guiding structure for the review of creativity research. Organizational creativity, divergent/convergent thinking, problem finding, and tolerance of ambiguity were emphasized. Attitudes toward creativity are environmental and subjective factors that shape creative behavior. It was suggested that when creative behaviors are desired there is need to (a) demonstrate that creativity is valued, (b) help students or employees understand that all humans have creative potential, and (c) clarify that creativity is not a fixed trait—it can be expanded and strengthened with practice.

Creativity is a process, and students of creative design should benefit when they understand that it is not a singular moment. It occurs over time and involves a mixture of subcomponents like divergent thinking, convergent thinking, and periods spent not consciously thinking about the problem.

The environment conducive to creativity has much to do with the authority figures' attitudes and how accepting they are of efforts to be creative. The creative behavior of students or employees often depends on their trust that creative behaviors are valued and respected. Attitudes that convey a need to be "correct" most of the time do not support environments conducive to creative behavior. Also, physical characteristics of the environment can promote or inhibit creativity. In general, people seem to prefer visually intricate textual patterns, natural light, and interior designs that encourage social interaction.

The assessment of creative products in their final state is not an optimal approach to understanding or helping students to learn about the creative process. Students might benefit as a result of formative interventions to support creative process instead of summative assessments of their final output. This might include conceptual support such as helping students recognize the difference between incremental and radical innovation. That is, products can be highly creative without being entirely new. Most creatively designed products are iterations of existing design ideas. Beliefs that a thing is creative only when it is entirely new is a myth held by many laypersons that can hamper creative efforts. Understandings the iterative, cultural, and social aspects of the creative process are more likely to improve the creativity of students than stand-alone assessments of final work.

Products *do* offer insight into the creative process when their creation is studied. As was observed, students who took extra time to frame and organize their approach to a task had a higher likelihood of generating creative products. This initial approach to a task was described as a discovery orientation that supported problem finding ability.

Organizational creativity combines ideas from the body creativity literature and orients them toward the facilitation of creative work environments. For example, design thinking is one of several forms of organizational creativity strategies used in professional contexts. Amabile's (1982, 1996, 2019) research surrounding creativity in professional work environments is valuable and can inform efforts to teach creativity in higher education. Her work concerning assessment via the consensual assessment technique and her research into the social, affective, and motivational factors that shape creativity offers insights that can inform interventions seeking to nurture creative design ability.

Divergent and convergent thinking are associated with the quality of creative outputs. These two thinking styles both contradict and complement each other, and it is possible to form creative teams that group those together who have dispositions toward either one or the other thinking skills. Also, the creative process is not only divergent thinking. Otherwise, the creative process would never produce results. Both divergent and convergent thinking are necessary for a complete creative process, and so both thinking styles should be practiced.

Problem finding and a tolerance of ambiguity were suggested as essential parts of the creative process. Resistance to closure and discovery orientations were seen to correlate with high levels of creativity. Moreover, the problem and the solution in a problem space tend to reformulate during the creative process, and a tolerance of ambiguity is obviously important for this kind of co-evolution of the problem and solution to occur.

This section developed aspects of creativity that overlap with design. The next section will develop the concept of design.

Design

This section of the literature review will historically and theoretically situate design thinking in higher education today. This review begins with a broad socio-cultural and historical consideration of design activity. Next, the history and evolution of design theory will be traced from its inception in the 1950s to its current state with an emphasis on its application to higher education. After this, design will be considered in its relation to problem types. Then, design will be considered in its relation to models and modeling. The discussion will then focus on what is being called “design thinking” with attention towards its components, its application in higher education, and emerging issues.

Is it not apparent that the Latin roots of the word design— “point out, mark out, and sign”—suggest hand movement? Now consider Vygotsky's (1978) use of a hand gesture in his example of *internalization.* After a child’s repeated and unsuccessful grasping at an object, the mother retrieves the object for him. Through this simple social experience, the child learned a new power, once the external grasping became internalized and meaningful for the child. This example is a microcosm of how the practical activity of design connects with learning.

Moreover, the child's learning stemmed from its ability to detect a difference within a specific context. Today's cognitive science research also reflects this ability to learn from detected differences in experience. Hierarchical, action-oriented predictive processing models have suggested that "In particular, one of the brain's key tricks, it now seems, is to implement dumb processes that correct a certain kind of error: error in the multi-layered prediction of input" (Clark, 2013, p. 181). Detecting a difference, relating it to a social context, and linking it to an object was the developmental process that resulted in the child's new ability to make a sign, to point out, to designate. This triangular mechanic that Vygotsky described—the subject, object, and mediating artifact (tools, signs)—involves a core mechanic of the design process. Maybe a big part of design is the ability to notice differences and respond to them in ways that improve circumstances. In any case, it seems like design is intimately bound with learning.

Zooming to microscopic detail to find a definitive "essence" of the design process is tempting. However, even the smallest design actions seem to "reach out" to the world, and so the *context* of design activity has so much to say about design ability. Because design is bound between designer and the context, design has an adaptive, changing quality. A proper study of design might not be isolated from the "great blooming, buzzing confusion" (James, 1890, p. 488) of the world. Design exists as history, as an academic subject, as practice, and as theory (Dilnot, 1984). How and why did this fundamental part of being human evolve to be the thing that some label "design thinking?"

Attempts to neatly trace the history of design are complicated by the fact that design has had multiple points of origin. Just as the design process is opportunistic and unpredictable (Cross, 1999), so is its history. "Design history arises, in the service of design, as a response to particular practical problems. It does not arise artificially, simply for the sake of itself" (Dilnot, 1984, p. 9). It is for this reason that a single and coherent history of design as an organized discipline "*does* *not exist*" (p. 11) and that it is "bafflingly difficult" (p. 12) to organize a summary of design history.

Design-oriented thinking may have first emerged as an unconscious action around 250,000 years ago during the Middle Stone Age (Broadbent, 2003), but the theoretical development of design ideas can only be traced to 40 BC and the rule of Emperor Augustus, during which time Vitruvius—Roman writer, architect, and engineer—wrote *De Architectura*, a 10 chapter encyclopedic treatment of city planning, engineering, and Roman architecture and the only work on architecture to have survived antiquity (Vitruvius, 2019). Aside from architecture, design as a historical activity was apparent in the decorative arts. This category includes monumental architecture, houses, excavated utensils, tools, and crafted objects of furniture, glassware, ceramics, and so on (Dilnot, 1984). The taxonomy of these design artifacts provides a descriptive catalog, but it lacks design rationale and information about the process. Broadbent (2003) characterized this early generation of design as craft methods, where the transmission of information was constrained to the apprenticeship model. There were no drawings and no explicit reasoning. Revisions were made through trial and error; there was no way to store the information except in the product itself, and this made design a costly and slow activity.

The next generation of design came from architecture in the mid-1450s and introduced design-by-drawing. Drafting allowed design to be abstracted from production, which revolutionized practice and led to a division of labor which made complex designs possible. However, since solo designers mostly accomplished the drawings, the design process stalled when products became more complex and eclipsed the expertise of solo designers. Also, the dynamics of physical relationships did not translate well from drawings.

During the 19th century's rise of industrialism, design theory saw rapid growth within the field of mechanical engineering which sprawled into new specializations—chemical, electrical, electronics, and software (Le Masson, Dorst, & Subrahmanian, 2013). For Dilnot (1984), design emerged into popular consciousness during the 1950s and 1960s via the “consumer revolutions of the post-war period, the institutionalization of design, the expansion of art and design education, and the explosion of youth and pop cultures” (p. 10). Design and style came to be recognized in mainstream culture and “this cultural identification with things also marked an acceptance of industrial culture” (p. 10). This cultural meta-awareness of design was also been reflected by the work of the surrealists, notably with Magritte's *The Treachery of Images* (1929.) This example of a popular meme demonstrated a sophisticated awareness of the contradiction between the object of design and its representation.

As a result of the industrial age, design expanded from individual craftsmanship into a collective, industrial activity. With this expansion, design intertwined with everyday life and the broad socio-cultural, economic, and political landscape. In response to the increased scope and complexity of context, design methods began to target severe social, economic, and environmental problems. But design methods were not unified—the fragmented and domain dependent character of design theory and practice was the norm. As different professional domains have served as intellectual hubs for design theory, each domain of practice “was accompanied by the development of its own appropriate design tools and theories” (Le Masson et al., 2013, p. 98).

Origins of design discourse: 1950s-1960s. In the 1950s, the systems method of design originated in West Germany at the Hochschule für Gestaltung, Ulm (Broadbent, 2003). Rittel and others first introduced the systems method at the First Conference on Design Methods held in London in 1962. Rittel continued teaching and theorizing design methods and relocated to Berkeley in 1963. After realizing the limitations of these methods, he railed against them in the early 1970s and used problem types as the lens for describing design methodologies. This first instance of systems design was called *hard system methods*, which had its beginnings in operational research and management science related to military and commercial applications in the 1930s. When these methods were first applied as hard systems design in the 1950s and early 1960s, their inability to satisfactorily address real-world issues and complexities engendered sharp criticisms.

Hard systems methods were grounded in the natural sciences. They were objective, rigid, linear, and poorly suited to the management of complex and unclear problems. In response, a different systems approach, grounded in social sciences, was developed. These were called *soft system methods*. A table comparing the hard and soft systems design methods is reprinted (Broadbent, 2003) in Table 7.

Table 7

Hard Systems Methods vs. Soft Systems Methods

Hard Systems Methods (HSM)	Soft Systems Methods (SSM)
Grounded in natural sciences	Grounded in social sciences (action research)
Reductionist, determinist, testable	Holistic, purposeful, judgmental, intuitive, descriptive, conjectural, normative, a matter of perception
‘Objective’, theory-based, positivist, functionalist	Subjective, wisdom/values-based, experiential, empirical, pragmatic, phenomenological, hermeneutic, action-based
Inductive, logical, rational, methodical, bottom-up	Abductive, inferential, intuitive, top-down and bottom-up
Suitable for isolated, relatively simple systems/highly specific problems; ‘tame’ problems	Suitable for highly interactive, complex systems/problems; ‘wicked’ problems
Directly involved in real-world; ontological; views systems as real	Simulates real-world through models; epistemology dependent
Stepwise, linear, sequential	Iterative, non-linear
Surprise-free	Emergent
Methodology-driven, prescriptive	Largely guided by informal human judgement, situation driven
Optimizes, singular outcomes	Satisfices, pluralist outcomes
Static	Evolutionary
Address rare human situations	Address common human situations
Intervention-based	Interactive
Externally applied to system	Internalized by system
Systematic	Systematic and systemic
Explicit	Tacit; implicit

Note: From "Generations in Design Methodology." by J. Broadbent, 2003, The Design Journal, 6, p. 7. Copyright 2003 by Taylor & Francis. Reprinted with permission.

This comparison table both indicates the way design theory was split between the natural and the social sciences and how design theory would evolve in these two areas. Tensions remained between these two paths, and yet they would comingle and share ideas in the coming decades.

The early generation of design methods took hold in the domains of cybernetics, information theory, and decision science—with notable outputs being the *General Problem*

Solving Program I (Newell et al., 1959) and *The Sciences of the Artificial* (Simon, 1969). Work from this decade was characterized by the establishment of systems thinking to manage complexity and make decisions. Simon's (1916-2001) work focused on decision science and emphasized the use of computers as tools for decision making and design. His work with Newell resulted in one of the earliest computer programs aimed at problem-solving and originated the field of artificial intelligence. Simon had much to say about design, but the scope of his work was more extensive and included systems theory, especially complexity and hierarchic systems. Simon's ideas were integrated with his practice, as opposed to design theoreticians, like Rittel, whose work was purely theoretical.

As many scholars and practitioners of design (Archer, 1979; Buchanan, 1992; Kelley & Kelley, 2013; Leifer & Meinel, 2015), Simon also saw design as a significant component of educational systems. He noted the interdisciplinary nature of design and lamented that in the decades after WWII it was nearly eliminated from the curriculums in engineering, medicine, and business:

> Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design (p. 111).

He viewed the proper way to study humankind was through the ways it carries out design: "the proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated person" (p. 138). From an application standpoint, he believed design theory should be made explicit so that computers could be more effectively integrated with research, education, and practice. His perspective on design theory was mainly oriented to its relationship with computers, "In substantial part, design theory is aimed at broadening the capabilities of computers to aid design, drawing upon the tools of artificial intelligence and operations research." (p. 114). Simon discussed different ways which computers can be applied to design problems, often centering the examples around his General Problem Solver (GPS) computer program.

Simon's discussion of design involved a mostly linear, hierarchic process. There was consideration of some lateral moves (de Bono, 1969, 1985, 1992, 1995) and decision making within given sets of alternatives and responsive to context. Still, much of the design process he described involved setting parameters that significantly defined and framed the problem, and this kind of work, arguably, is where the real work of problem-solving occurs—and then computers can run computations. And yet Simon theorized ideas for software design that fit with a soft systems approach, such as co-operative design (Bφdker, Grφnbæk, & Kyng, 1995). For example, this user-driven design for a hypothetical city planner:

> We have usually thought of city planning as a means whereby the planner's creative activity could build a system that would satisfy the needs of a populace. Perhaps we should think of city planning as a valuable creative activity in which many members of a community can have the opportunity of participating if we have wits to organize the process that way. (p. 130)

Like others (Buchanan, 1992), Simon predicted more people would become designers as part of their everyday routines as computers became commonplace, "The ability to communicate across fields the common ground comes from the fact that all who use computers in complex ways are using computers to design or to participate in the process of design." (p. 137). As students in management information systems first began to use computers as design tools, Simon observed the related computer applications tended to overload the user with information, negating their effectiveness. He described how parameters could be set to restrict information and improve the usefulness of the computer as a design tool when coping with vast amounts of information. Simon's view of the design process was characterized by either (a) using the computer as a design aid or (b) programming computers as design aids.

When viewing design from a societal perspective, Simon considered the problems of complexity and information:

> The real design problem is not to provide more information to people but to allocate the time they have available for receiving information so that they will get only the information that is most important and relevant to the decisions they will make. The task is not to design information-distributing systems but intelligent information-filtering systems. (p. 144).

More than most other design scholars in this review, Simon combined theory with invention. His ideas were grounded in authentic design activities involving either users or programmers. In this way, he was like Edison. He took a broader view of society and noted that designers needed to understand their clients would often take on the designer role, "The members of an organization or a society for whom plans are made are not passive instruments, but are themselves designers who are seeking to use the system to further their own goals" (p. 153). This thinking extended to a consideration of the fluidity of the problem-solution space in design, where the process of design required designers to be flexible and allow the design path to reveal itself:

> Making complex designs that are implemented over a long period of time and continually modified in the course of implementation has much in common with painting in oil. In oil painting every new spot of pigment laid on the canvas creates some kind of pattern that provides a continuing source of new ideas to the painter. The painting process is a process of cyclical interaction between painter and canvas in which current goals lead to new applications of paint, while the gradually changing pattern suggests new goals. (p. 163).

Simon was an influential figure of the early generation of design theorists. Along with an emphasis on the representation of design problems in multiple ways, he outlined six topics important to any efforts toward design education:

1. *Bounded rationality*. The meaning of rationality in situations where the complexity of the environment is immensely greater than the computational powers of the adaptive system.
2. *Data for planning*. Methods of forecasting, the use of prediction and feedback in control.
3. Identifying the client. Professional-client relations, society as the client, the client as player in a game.
4. *Organizations in social design*. Not only is social design carried out mainly by people working in organizations, but an important goal of the design is to fashion and change social organization in general and individual organizations in particular.
5. *Time and space horizons*. The discounting of time, defining progress, managing attention.
6. *Designing without final goals*. Designing for future flexibility, design activity as goal, designing an evolving system" (p. 166).

Simon's work to manage complexity via computers and systems thinking birthed the field of artificial intelligence. Although new socially focused trends in design branched away from purely scientific approaches, the evolution of hard systems continued. For example, application of systems design methods within the field of engineering (Jones, 1963; Jones & Thornley, 1962) would continue to evolve alongside other design methods (Cross, 1986). In the 1960s, decision science prevailed over the development of design theory until a shift towards the unification design theory according to scientific method took place in the 1970s (Cross, 1984; Le Masson et al., 2013). This co-occurred with systems theory and computer-aided design in the 1980s. In the 1990s, agent-based systems and situated cognition became prominently associated with design theory. More recently, the link between design theory and neuroscience has been pronounced (Le Masson et al., 2013). Within the field of engineering work to create an ontology of design has continued to “reconstruct the science of design, comparable in its structure, foundations and impact to decision theory, optimization or game theory in their time” (Hatchuel, Le Masson, Reich, & Subrahmanian, 2018, p. 5).

Bruce Archer (1922-2005) was a significant figure in the early generation of designers and framed discussions that continue today. Working in the field of industrial design and education, he was tuned into the ways design was changing and the implications those changes held for the practice of design. His experience with computers during the 1950s led him to be increasingly optimistic about the application of computerization and systems methods to the practice of creative design (Davis & Gristwood, 2016). Writing from the field of industrial design and education, Archer (1963) developed his early design ideas in the Central School of Arts and Crafts and Royal College of Art in London as well as in West Germany at the Hochschule für Gestaltung, Ulm. After attending the First Conference on Design Methods held in London in 1962, the same conference mentioned earlier in reference to Rittel, Archer wrote a series of articles that introduced a systems approach to design.

Archer (1963) described an increasing complexity of design practice where "habitual rules of thumb" for product design expanded to include "a systems approach as distinct from an artifact approach...[and] a worldwide shift in emphasis from the sculptural to the technological" (p. 47). He probed the connection of aesthetics and ethics and began the discussion with a consideration of aesthetics as a "theory of the perception of the beautiful" (p. 48) and the problem of "good" and "bad" taste. Research efforts to measure the variation in peoples' perception of what is "good" or "bad" led Archer to divide aesthetics into descriptive aesthetics, "which deals with the empirical facts about perceivable qualities and the statistics of preferences" and ethical aesthetics, "which deals with good taste and bad taste, or appropriateness" (p. 48). He broadly described descriptive aesthetics as "natural science, like physiology" and ethical aesthetics as "practical science, like philosophy" (p. 48).

For design practice, natural science intertwines with practical science. Whereas natural science is used to understand the nature of phenomena without passing judgment, practical science involves considerations of use, appropriateness, and helping people choose what to do. Technology was being used more and more to help people make decisions and was primarily concerned with the means of that accomplishment. Ethics was concerned with the ends of that accomplishment and was therefore "an essential element not only in the practice of aesthetics but also in the practice of any profession which is involved with the exercise of any form of judgment" (p. 49).

Archer used Burgundy wine to describe how value judgments are often used to gradually build criteria or standards, which can then take the shape of established law and are sometimes perceived as "hard scientific fact" (p. 49). The determination of the acceptable level of alcohol for a class defined as Burgundy was a matter of descriptive aesthetics and ethics. It was a matter of measurement and agreement that did not involve value judgments. Determining whether a batch of Burgundy was "good" or "bad," however, involved practical, or ethical, aesthetics because value judgment was involved. For Archer, developing systematic criteria for passing judgment did not necessarily involve value judgments and may not be consciously recognized, but the final application of those criteria for deciding as to whether the wine was good or bad did involve practical ethics and values.

This process evolved democratically. Definitions for what is good or bad shifted based on what qualities wine drinkers found acceptable. If flavors shifted toward dryness and the wine tasters found it acceptable or pleasing, the basis for judgment would shift. Next Archer turned the discussion toward exploratory behaviors. He was most interested in those people who found "pleasure in exploring the perimeter of current experience" (p. 49). These were the people who would push the boundaries of taste and functioned as tastemakers that others would follow, and he concluded: "'They' are the people who are found to be most worth imitating at a given moment with respect to a given activity" (p. 49).

Archer's discussion was intended to show that while there are no immutable truths for designers to follow, systematic methods could still inform design decisions. "The essence of aesthetics is choice, the aim is appropriateness, and the criteria are the center of gravity and the periphery of all the choices made so far" (p. 49). With subjectivity taking such a significant role in the determination of what counts for good or bad, designers were faced with an ill-structured problem. "The designer's special problem is that the must usually foresee the probable future choice of other people as well as his own" (p. 49).

Archer looked for ways to apply non-quantitative mathematics like Boolean algebra (2019) to design decision processes, similar to how case law is constructed. Boolean algebra was different from numerical logic. As intensely optimistic as Archer was in the pursuit of a science of design, he admitted, "this is not to say that experience, intuition and judgement should henceforth be abandoned or in any sense devalued" (p. 49). Archer claimed that in most cases, intuition was the best approach to design problems. And yet, Archer claimed, "that it is possible to reduce the area of the unknown and to define by systematic examination those elements in the problem which should properly be judged intuitively" (p. 49). This tension concerning the nature of design persists as an expression of beliefs along a continuum, with design as intuition at one end and design as science at the other.

Archer's opinions on the use of systems methods for design changed dramatically during his lifetime. After becoming disillusioned with the idea of turning design into a science of systematic methods, Archer came to see design as most useful as a part of general education (Davis & Gristwood, 2016). In an ironic twist of fate, the Royal College of Art, where Archer had ascended, would eventually shutter its Department of Design Research:

> When Jocelyn Stevens became Rector at the RCA in 1984, he closed the Department of Design Research. For George Mallen (2011), the effect was to "almost annihilate any intellectual activity in the College." Stevens kept Archer on while sacking all his staff. "It broke Bruce's heart" in the opinion of Christopher Frayling (2013). Archer's insistence that he was not trying to help practising designers almost certainly told against him – he paid the price for such honesty. The other departments stood by and watched the Department close. At Senate, "nobody said a word. They were just relieved it wasn't them" (Frayling 2013). (Davis & Gristwood, 2016, p. 13)

Today, the Royal College of Art supports a school of design (2019) that offers programs that emphasize products, fashion, engineering, mobility, healthcare, service, textiles, and a variety of research pathways.

The 1950s-1960s scientific orientation of design methodologies would come to be harshly criticized. Emerging social and environmental problems created tensions within the professional practice of design. These tensions resulted in contradictions when existing design practices no longer seemed adequate in meeting human needs. Pioneers of systems methods for design like Archer, Simon, and Rittel would witness systems methods undergo a stress test in the coming years and, like most designers, revise their ideas. Over time, the outcome was human-centered design.

Emerging complexity: 1970s. Like lights bouncing off the many facets of a spinning disco ball, emerging social, economic, and environmental issues swirled a disarray of challenges that over-stressed hard systems methods. Rittel and Webber (1973) described the severe issues as *wicked* problems and claimed that the methods of science were not compatible with those problem types chiefly situated in societal issues. Recall it was Rittel and others that first introduced the hard systems method at the First Conference on Design Methods held in London in 1962 (Broadbent, 2003). Existing design methods rooted in scientific problem solving were criticized as inappropriate to the task of addressing social issues, which generated different kinds of problems that required different kinds of problem-solving strategies.

The need for a well-defined problem for design theory to work was the weakness of the earlier systems approach to design. Kunz and Rittel (1972) described the shortcoming:

> The classical systems-approach of the military and the space programs is based on the assumption that a planning project can be organized into distinct phases. Every textbook of systems engineering starts with an enumeration of these phases: "understand the problems or the mission," "gather information," "analyze information," "synthesize information and wait for the creative leap," "work out solution," or the like. (Rittel & Webber, 1973, p. 33)

A defining characteristic of wicked problems was ambiguity, which made an initial problem definition unreasonable: “The formulation of the problem is the problem” (Rittel & Webber, 1973, p. 161)!

Writing from the field of information science, Kunz, Rittel, and Webber (1972;1973) coined the term wicked problems to strike a contrast between the types of problems faced by scientists and engineers and the types of problems faced by the social professions. They claimed that American society and the social professions had been misled to believe that social problems could be solved using the same methods used by scientists and engineers. They described the problems facing engineers as generally well-structured and problems facing the social professions as ill-structured, or wicked, problems. Well-structured problems were described as those problems that presented themselves clearly and had a clearly defined solution.

These kinds of problems were “tame” or “benign.” Wicked problems were the opposite and typically involved social policy issues. Churchman (1967), a colleague of Rittel, described wicked problems as “that class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing” (p. 141). The term wicked was not meant to imply the problems themselves were “ethically deplorable” but that minimizing wicked problems might be:

> But then, you may agree that it becomes morally objectionable for the planner to treat a wicked problem as though it were a tame one, or to tame a wicked problem prematurely, or to refuse to recognize the inherent wickedness of social problems. (Rittel & Webber, 1973, p. 161)

The ten characteristics of wicked problems listed in the article are reprinted in Table 8.

Table 8

Ten Characteristics of Wicked Problems

Characteristics of wicked problems
There is no definitive formulation of a wicked problem.
Wicked problems have no stopping rule.
Solutions to wicked problems are not true-or-false, but good-or-bad.
There is no immediate and no ultimate test of a solution to a wicked problem.
Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
Every wicked problem is essentially unique.
Every wicked problem can be considered to be a symptom of another problem.
The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
The planner has no right to be wrong.

Note: From "Dilemmas in A General Theory of Planning." by W. J. Rittel, and M. M. Webber, 1973, Policy Sciences, 4, pp. 161-166. Copyright 1973 by Springer New York LLC. Reprinted with permission.

Rittel and Weber's reason for listing these characteristics was to clarify the ill-defined and ill-structured nature of the societal problems facing the social professions and the growing disillusionment in America's promise of liberty and equity. "Candide is dead. His place is being occupied by a new conception of future history that, rejecting historicism, is searching for ways of exploiting the intellectual and inventive capabilities of men" (pp. 157-158). Disillusionment with the Vietnam war was growing. The Watergate scandal wore on. The energy and oil crises continued to squeeze. Post-WWII American optimism was fading in the face of unresolvable problems. Design methodologies that had once satisficed were losing their effectiveness:

> The professionalized cognitive and occupational styles that were refined in the first half of this century, based in Newtonian mechanistic physics, are not readily adapted to contemporary conceptions of interacting open systems and to contemporary concerns with equity. (p. 156)

The authors continued to enumerate and elaborate the ways in which the new breed of wicked problems was not solvable by a scientific approach to problem-solving and concluded that "the problems that planners must deal with are wicked and incorrigible ones, for they defy efforts to delineate their boundaries and to identify their causes, and thus to expose their problematic nature" (p. 167).

The authors described the deficiencies of current systems well enough but did not suggest alternatives beyond a rejection of current practices. Maybe it is asking too much of the ones who introduced the very systems approach they now criticized to offer any optimism, but at least they acknowledged they were out of ideas:

> We have neither a theory that can locate societal goodness, nor one that might dispel wickedness, nor one that might resolve the problems of equity that rising pluralism is provoking. We are inclined to think that these theoretic dilemmas may be the most wicked conditions that confront us. (p. 169)

Forty years after this article was published, Farrell and Hooker (2013) challenged the use of "wicked" versus "tame" problems as a way of segregating one kind of problem to design and another to science. They argued the wicked-tame dichotomy was false and non-productive. The dichotomy set up between tame and wicked problems and thus cognitive versus conative design might be unrealistic and unhelpful. For these authors, methodological extremes between scientific and social orientations may yield less value than a mixture of both orientations.

> A subsequent position accepts that science is norm-driven but claims that the norms in science are distinctively cognitive in character whilst the values that operate in design are distinctively conative or pragmatic in character, and therefore their core cognitive processes are correspondingly different. Specifically, it is the intentional accommodation of distinctively human desires and preferences in design, in contrast to their intentional exclusion from science, that is held to distinguish the two activities. But the differences between norms in design and science are irrelevant to the issue of whether design and science share a core cognitive process in common. It matters only that both processes take the form of a strategic pursuit of value constrained by satisfying a collection of norms. (Farrell & Hooker, 2013, pp. 700–701)

For these researchers, 40 years of hindsight led to the idea that the methodological divide was a self-serving and false dichotomy that distracted from design's purpose of creating value. But during the 1970s, there was a strong reaction against hard systems methods from the very people who had used them.

Archer (1979) reflected on how the "mathematical and flow-chart type models" (p. 17) that design theorists advanced were rejected by working designers because they imposed an inhuman structure on design activity:

> …mathematical or logical models, however correctly they may describe the flexibility, infectiveness and value-laden structure of the design process, are themselves the product of an alien mode of reasoning. My present belief, formed over the past six years, is that there exists a designerly way of thinking and communicating that is both different from scientific and scholarly ways of thinking and communicating, and as powerful as scientific and scholarly methods of inquiry, when applied to its own kind of problems. (p. 17)

For Archer, the early theories of design methods dislocated analysis from synthesis and were too linear and oriented toward causalities. The ill-structured problems with which design engaged were common to everyday experience and so, "Not surprisingly, in the course of evolution, human beings have found quite effective ways of dealing with them. It is these ways of behaving, deeply rooted in human nature, that lie behind design methods" (p. 17). He described how the problems with which design dealt did not quickly reveal themselves and defined an ill-defined problem as “one in which the requirements, as given, do not contain sufficient information to enable the designer to arrive at a means of meeting those requirements simply by transforming, reducing, optimizing or superimposing the given information alone" (p. 17).

Another deficit of the early design methods was language. Words, mathematics, or scientific notation were inappropriate ways to describe and communicate design. The way people design involved a cognitive system that was different from the language system and centered around modeling. "Thus, design activity is not only a distinctive process, comparable with but different from scientific and scholarly process, but also operates through a medium, called modeling, that is comparable with but different from language and notations" (p. 18).

In a short article, Archer summarized some significant issues with design theory—ill-structured problems, the ambiguous nature of the problem and the solution, and the importance of modeling along with the problem of inappropriate representations of the modeling process when achieved through conventional means.

Cross (1982) introduced the phrase “designerly ways of knowing” as a way of summarizing the cognitive abilities of designers:

1. Designers tackle ‘ill-defined’ problems.
2. Their mode of problem-solving is ‘solution-focused.’
3. Their mode of thinking is ‘constructive.’
4. They use ‘codes’ that translate abstract requirements into concrete objects.
5. They use these codes to both ‘read’ and ‘write’ in ‘object languages.’

For Cross, these abilities lent themselves to an interdisciplinary approach to education, and he reasoned that design-oriented education had essential advantages over the conventional approaches to education:

1. Design develops innate abilities in solving real-world, ill-defined problems.
2. Design sustains cognitive development in the concrete/iconic modes of cognition.
3. Design offers opportunities for development of a wide range of abilities in nonverbal thought and communication (p. 226).

A literature review conducted by Cross (1986) summarized positions in the preceding 20 years of design methodology. His review resulted in four categories that related to design methodology. The categories were: (a) the management of design process, (b) the structure of design problems, (c) the nature of design activity, and (d) the philosophy of design method (p. 409). Respectively, these categories emerged and developed in a chronological sequence. The two-dimensional continuum represented by design as natural science on one end and design as social science on the other end continued to prevail over design theory generally. The driving rationale for the 1950s-1960s generation of design methods was characterized as "A concern with increasing both the efficiency and the reliability of the design process in the face of the increasing complexity of design tasks" (p. 415). Desires to operationalize and reduce design to a universal, algorithmic set of laws persisted in the face of arguments that design could not be appropriately understood using methods that were reliable and valid in the physical sciences. Cross concluded the current state of design methods was a "clash of views between those who want to develop an objective 'design science' and those who want to reconstitute the design process in recognition of the ill-defined, wicked, or ill-structured nature of design problems" (p. 421).

Design is contextual, and academic debates do not happen in a vacuum—they connect with the socio-cultural-historical context. Meanings that characterized the period’s culture were reflected in the design and manifestations of popular art reflected the tensions and clashes happening in design. For example, Gene Roddenberry's television series *Star Trek* (1966-1969) embodied tensions between scientific rationality and emotionally driven human behavior with the characters of Spock and Captain Kirk, respectively. Moreover, since the industrial revolution technology's impact on human life had grown exponentially. However, technology's horrific expression in 1945, when the United States killed hundreds of thousands of Japanese people with two thermonuclear bombs, brought the relationship between science and humanity to a critical point. The unbridled power of technology became the concern of the age. Director Stanley Kubrik explored these themes in *Dr. Strangelove or: How I Learned to Stop Worrying and Love the Bomb* (1964) and *2001: A Space Odyssey* (1968). Design and human activity are inseparable, and it is only natural that design theory reflected the emerging contradiction between the well-being of humanity and technology's power of altering the world for good or ill.

The design discourse continued to splinter as each camp further articulated its position. Thomas and Carroll (1979) held that design was a "generalized form of problem-solving which can be applied in a wide variety of contexts" (Cross, 1986, p. 427), which was mostly the same perspective on design proposed by the earliest generation of systems design. That is, the belief in contextually independent design methods that could apply universally across all design domains. Alternative methods of investigating design that developed in response to dissatisfaction with scientific methods for explaining design were reviewed and consisted of (a) interviews with designers (Darke, 1979) and (b) protocol analysis of design process (Akin, 1979).

A final category of analysis was the philosophy of design and the position that, if current design practices were insufficient, then there was little to be gained by observing them. Academics within this area of design theory found themselves in disagreement and held that design was a rational process (Hillier, Musgrove, & O'Sullivan, 1972), that design was abductive logic or productive reasoning (March, 1976), or that design was creativity (Daley, 1982). Broadbent (1979) proposed that "there cannot be any true theories of design as such, and so design will continue to be susceptible to pseudo-theories…design activity is more difficult than scientific activity" (Cross, 1986, p. 433). Cross's review concluded with a reprise of the evolution of design theory as four major sequential categories of development. The categories involved *prescription* of design methods from the earliest phase, *description* of design problems in the next phase, *observation* of design activity in the third phase, and *reflection* on the fundamentals of design in the fourth phase.

The 1970s represent the beginnings of a paradigm shift in the way design was theorized and practiced. The decade began with incisive criticism of the first generation of design methods (Kunz & Rittel, 1972; Rittel & Webber, 1973) and unfolded with philosophical debates resembling a hall of mirrors; each theoretical position offering its unique perspective on design. The next generation design theory would embrace the complexity of ill-structured societal problems, and the recurrent theme of design as education would enjoy continued support from a variety of domains.

The emergence of design thinking: 1990s. Similar to Archer (1979), Buchanan (1992) saw design thinking as education: "…for we have seen design grow from a *trade activity* to a *segmented profession* to a *field for technical research* and to what now should be recognized as a new *liberal art of technological culture*" (p. 5). Buchanon distinguished between technology as an object and technology as an art, or way of thinking. He believed that

> Most people continue to think of technology in terms of its *product* rather than its form as a *discipline of systematic thinking*. They regard technology as things and machines, observing with concern that the machines of our culture often appear out of human control, threatening to trap and enslave rather than liberate. But there was a time in an earlier period of Western culture when technology was a human activity operating throughout the liberal arts. Every liberal art had its own *technologia* or systematic discipline. To possess that technology or discipline of thinking was to possess the liberal art, to be human, and to be free in seeking one's place in the world. (p.19)

For Buchanan, design also had technologia which was it the process of planning for new products. He claimed design was "emerging as a new discipline of practical reasoning and argumentation, directed by individual designers toward one or another of its major thematic variations in the twentieth century: design as *communication*, *construction*, *strategic planning*, or *systemic integration*" (pp. 19-20).

He believed the real power of the design process was its independence from the traditional modes of expression, language, and numeracy. The activity of design overcame the separation of "theory and practice that remains a source of disruption and confusion in contemporary culture" (p. 20). Buchanan believed the traditionally separate domains of design practice would blur. Those areas were:

1. the design of symbolic and visual communications
2. material objects
3. the design of activities and organized services
4. the design of complex systems or environments for living, working, playing, and learning

These areas would integrate as designers recontextualized problem and solution spaces, "The ability of designers to discover new relationships among signs, things, actions, and thoughts is one indication that design is not merely a technical specialization but a new liberal art" (p. 14). For Buchanan, keeping the areas of design separate was a missed opportunity:

> But this would not be adequate, because these areas are not simply categories of objects that reflect the results of design. Properly understood and used, they are also places of invention shared by all designers, places where one discovers the dimensions of design thinking by a reconsideration of problems and solutions. (p. 10)

He said that as each domain appropriates design, it tends to regard design theory as its own, a historical trend that is seen around design since its earliest applications in industry. The argument was made for design theory as domain independent and part of a shift away from seeing technology as a product and more as a "discipline of systematic thinking" (p. 19). This was not to detract from domain-specific design theory but to point out that the hubris of a given domain regarding its design theory can overshadow opportunities for a cross-disciplinary theory of design.

For example, the way design was used in industrial design, engineering, and marketing entailed different goals where for industrial design the design vision was the *possible*, for engineering the design vision was the *necessary*, and for marketing the design vision was *contingent* upon users. On the surface the way the three professions use design seemed mutually exclusive, but as a new liberal art, Buchanan argued for design thinking as "communication, construction, strategic planning, or systemic integration" (p. 20) that involved the integration of the multiple perspectives.

It was necessary to integrate multiple perspectives that may seem contradictory or "impossible," but extremely ill-structured, wicked problems demanded new approaches to problems and solutions. Buchanan saw the approach of a neoteric, or newly emerging, art of design that advances in technology would enable for everyday people:

> But the masters of this new liberal art are practical men and women, and the discipline of thinking that they employ is gradually becoming accessible to all individuals in everyday life. A common discipline of design thinking-more than the particular products created by that discipline today-is changing our culture, not only in its external manifestations but in its internal character. (Buchanan, 1992, p. 21)

This trend has now established and is growing. Technology has fueled a bottom-up, user-centered design process that has challenged the traditional manufacturer's control over product design and created the phenomenon of user-centered innovation (von Hippel, 2005).

Since Buchanan’s article, design thinking has been used in higher education in combination with project-based learning. Writing from the field of engineering, Dym et al. (2005) described a design pedagogy termed the *Creative Gym*, which was a combination of project-based learning and design thinking methods and a strategy for improving outcomes for students of engineering. Their coverage of design thinking emphasized divergent-convergent questioning, systems thinking, uncertainty, estimating, experimentation, and collaboration. The course facilitated “design experiences” for engineering students and received high approval ratings backed with compelling anecdotal data. They found: (a) design contests were effective publicity and marketing tools, and (b) instructors needed to feel comfortable with project-based learning instructional approaches to effectively implement design education such as the *Creative Gym* course they described.

There were challenges in teaching the nuances of the creative design process. "...it is the framing of design decisions that is the most engaging part of doing design, as well as the most difficult to teach" (p. 105). One strategy for improved learning involved representing design problems in multiple ways. These included:

- *verbal or textual statements* used to articulate design projects, describe objects, describe constraints or limitations, communicate between different members of design and manufacturing teams, and document completed designs;
- *graphical representations* used to provide pictorial descriptions of designed artifacts such as sketches, renderings, and engineering drawings;
- *shape grammars* used to provide formal rules of syntax for combining simpler shapes into more complex shapes;
- *features* used to aggregate and specialize specified geometrical shapes that are often identified with specific functions;

- *mathematical or analytical models* used to express some aspect of an artifact's function or behavior, where this behavior is in turn often derived from some physical principle(s); and
- *numbers* used to represent discrete-valued design information (e.g., part dimensions) and parameters in design calculations or within algorithms representing a mathematical model" (p. 108)

Other characteristics students needed for successful course work included the abilities to:

1. tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking
2. maintain sight of the big picture by including systems thinking and systems design
3. handle uncertainty
4. make decisions
5. think as part of a team in a social process
6. think and communicate in the several languages of design. (p. 104)

The article concluded with a collection of research questions and assessment challenges framed by a contradiction. On the one hand, their teaching efforts using a hybrid of project-based learning and design thinking for engineering education was successful with improved student retention, student satisfaction, diversity, and student learning. On the other hand, it was expensive. Long-term faculty support of the efforts was questionable. There was a need to expand faculty to include those capable of teaching design. Facilities needed remodeling to support modern, project-based design courses. How could the improved outcomes associated with the course be reconciled with the higher costs?

Another level of challenges centered around the measurement and assessment of design thinking and creativity within the context of a project-based learning course for engineering students. How authentic did design projects need to be in comparison with professional practice?

How should interdisciplinary design teams be managed? Should the focus be on the quality of final projects or the quality of the design process? What emphasis should be given to individual cognitive development versus collective development?

To address the fragmentation of meaning for students in higher education, the team used a *folio-thinking* project design that had been tried out by Stanford, the KTH-Stockholm, and the University of Uppsala (Sweden). They found a key to this process was “a loop in which a ‘process expert’ is assigned to coach—but not direct or manage—a design team’s activity” (p. 113). Regarding the specifics of design thinking pedagogies, there was a challenge of integrating divergent/convergent inquiry into the engineering curricula. How exactly could convergent/divergent strategies be evaluated and how could this approach to creative design be authentically promoted within project work? The authors expressed a compelling argument for design education using the hybrid of project-based learning and design thinking methods that seemed very much like a work in progress. The most emphatic recommendation was that resources be prioritized and allocated expressly for “enhanced design pedagogy” (p. 114).

David Kelley, founder of IDEO and partner with Stanford’s d.school and the Hasso Plattner Institute for Design has experience teaching engineers in design courses. Hartfield (1996) interviewed Kelly and probed with questions about the differences between engineering and design. Kelley described the difference as a caricature of extremes—engineering as problem-solving on one end and design as creating on the other end. Engineers want to fix things, but designers want to go beyond the fix. “The designer has a dream that goes beyond what exists, rather than fixing what exists” (p. 153).

Kelley said that design is messy, but engineers have been taught to formulate problems in ways that clear away that messiness. Allowing the messiness to exist may contradict an engineer’s preferred way of thinking and be discomforting:

> The designer can handle the messiness and ambiguity, and is willing to trust intuition. Basically, design has to do with intuition. Engineers are prone to assume that intuition does not exist—that you can't make any creative leaps without proving the solution through the use of some equation…I'm just saying that the engineering profession has a self-image that it is based on mathematics and certainty. It justifies its status that way. (p. 154)

Kelley said that training could lead to good results and described a program at Stanford created for this very reason. "First, we loosen up the students—make them improvise, make them take risks, break cultural sets. People who are willing to loosen up can make great designers, but they have to be willing to take a chance" (p. 155). Kelley recalled a class where students were blindfolded and asked to walk about and feel for tree leaves.

> Trained engineers have trouble doing that kind of thing—they get upset. 'What are we doing? Why are we wasting our time?' They question the value, instead of going with the experience. Attitude is a result of training; but you can cross the line afterward—you can recover." (p. 155).

This kind of activity pushed students into behaviors that may not have been entirely comfortable, but there is a precedent in the creativity literature that goes far back. Csikszentmihalyi and Getzels (1971) observed that children who took their time in setting up a creative problem showed a discovery-oriented behavior that was associated with high creativity. Moreover, follow up studies many years later showed the problem finding skills still predicted high creativity in their work as adults (Runco, 2004).

Kelley continued to describe the differences between engineers and designers. "Design defines what it—whether it is drapes or software—ought to be. By contrast, engineering does it. Engineering is implementation." (p. 156). For Kelley, design can be uncomfortable for those who prefer a tactical certainty of action but dealing with unknowns can be practiced. Kelley likens it to the creative leap. "Who's good at leaping? People who have confidence. It's not that they are comfortable with it; they have just somehow been anointed with the ability to make this leap, and nobody is arguing" (p. 157).

That "nobody is arguing" has implications for educators. Amabile (1982), Amabile et al. (1996), and Amabile & Pratt (2016) have a large body of research that suggests an environment that supports the psychology of creative behaviors is required for creativity to occur. If students are asked to be creative on the one hand but on the other hand are held to standards that do not correspond, efforts to develop creative potentials are negated. Yes, design thinking has concrete methods to offer, but creative attitudes and behaviors that involve discovery and risk-taking are crucial and overshadow procedure. "You can't put design in a structure. You can't give a company a methodology manual…the typical design situation requires doing something you don't know how to do" (pp. 162-163).

Going beyond the given information is a creative design ability that has been described by Dorst (2011) through the lens of abductive reasoning. C. S. Peirce worked on the problem of abduction and "struggled for more than fifty years to lay bare the logic by which we get new ideas" (Fann, 2012, p. 5). Abductive logic is a form of reasoning more characterized by a creative leap rather than decision making that adheres to and is therefore bound by, a given set of data. Dorst (2011) used a series of logic models to represent "core concepts" (p. 522) of the kind of design reasoning that qualifies as design thinking, which involves a design ability to frame and reframe problem situations where only the aspired value is identified, but the actual problem or working principles involving its solution are unknown or vague. Figure 6 is slight adaptation of figures in the article.

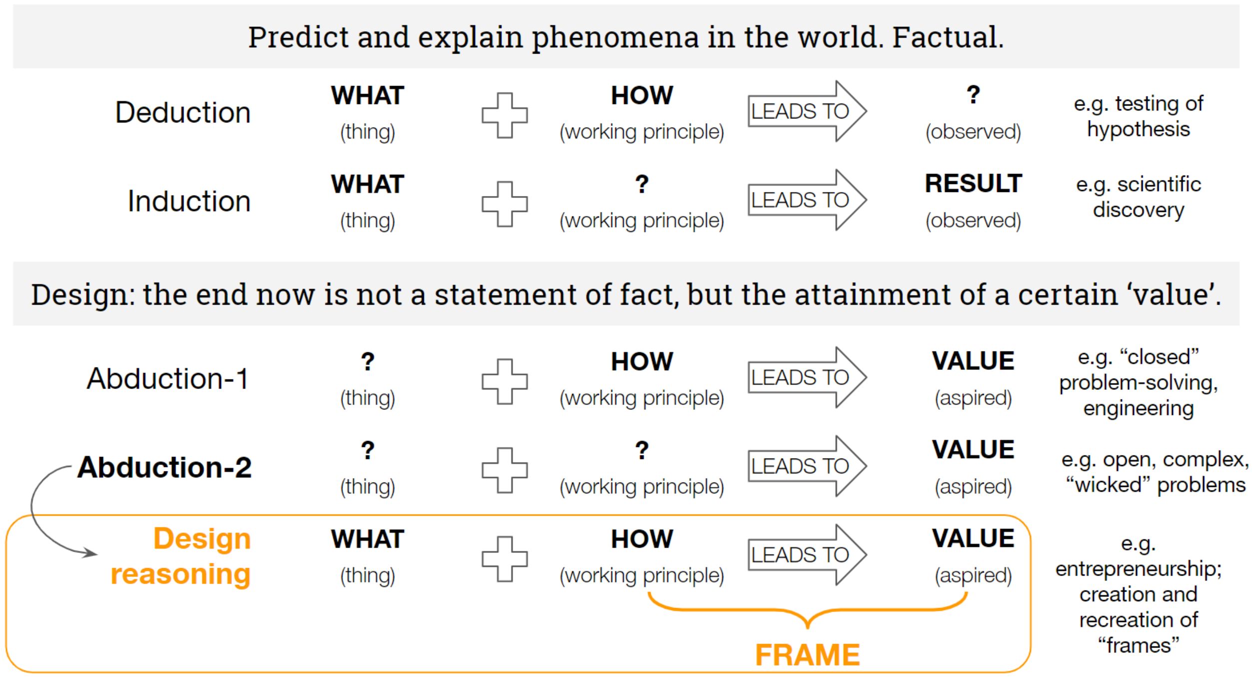

Figure 6. Deductive, inductive, and abductive reasoning patterns for problem-solving, design reasoning, and frame creation. Slightly adapted from "The Core of 'Design Thinking' and its Application." by K. Dorst, 2011, Design Studies, 32, pp. 523-524. Copyright 2011 by Elsevier. Reprinted with permission.

Deductive reasoning affords the possibility of prediction and allows thinkers to see the result while the "how" of the equation is unknown. Inductive reasoning happens when the "result" is known but the "how," or working principles, are unknown. The combination of inductive and deductive logic is fundamental to discovery and scientific reasoning. As for these formal logic types, neither induction nor deduction characterizes design thinking as well as does abductive reasoning.

Dorst (2011) considered abductive reasoning as fundamental to productive thinking. Designers typically needed to create value; the discovery of working principles was not enough. Abductive logic implicated a thinking process that creates value. There are two types of abductive reasoning: *Abduction-1* and *Abduction-2*. With *Abduction-1*, both the "what" and the "result" to be achieved is known, which represented a scenario analogous to traditional problem-solving. With *Abduction-2* logic, neither the "what" nor the "how" is known. Only the desired "value" exists.

This scenario requires designers to frame problems so they can achieve the desired values without further specifications and guidelines. For Dorst (2011), *Abduction-2* logic best represents the unknown and ill-structured problems that characterize much of the reasoning associated with design thinking. Characterizing design thinking problems as *Abduction-2* logic admits the unknowns of the process and opens a path for "…an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability, uniqueness, and value conflict" (Schön, 1983, p. 49). This view of the design process valued intuitive thinking over prescriptive thinking and emphasized the uncertainty inherent to design problems.

How designers respond to problems characterized by *Abductive-2* logic could reveal their ability to frame and reframe design problems as a creative strategy for navigating ambiguity within the creative design process. Dorst (2011) referred to this ability as *design reasoning* that was chiefly characterized by the designer's ability to frame and reframe situations and problems. "…frame creation as a core practice that is particular to the designing disciplines" (Dorst, 2011, p. 531). The idea of framing a situation to solve a problem was also addressed by Schön (1983), whose work emphasized that using a technical process for "solving" a problem is often insufficient and required the ability to rethink the problem setting and situation. "It is rather through the non-technical process of framing the problematic situation that we may organize and clarify both the ends to be achieved and the possible means of achieving them" (Schön, 1983, p. 41). Framing involved a reflection in and on the design space that Schön likened to a design conversation with the problem context.

> In a good process of design, this conversation with the situation is reflective. In answer to the situations back-talk, the designer reflects-in-action on the construction of the problem, the strategies of action, or the model of the phenomena, which have been implicit in his moves. (Schön, 1983, p. 79)

For Dorst (2011), *Abductive-2* reasoning framed a problem and once framed, a "what" was created to address the problem and achieve the desired values. At this point, since the designer used *Abduction-2* logic to reframe the situation or problem, *Abduction-1* reasoning can be used to converge upon solutions. Abductive-2 logic involved reframing the design problem in a way that cleared the path for more conventional problem-solving methods. Ultimately, Dorst admitted all forms of logical reasoning were relevant to design thinking, and the utility of using formal logic types to understand the core reasoning process associated with design thinking provided valuable constructs for research into the creative design process.

To investigate the effects of abductive reasoning on concept selection, Dong, Lovallo, and Mounarath (2015) developed a coding scheme for deductive, inductive, and abductive reasoning and set up a series of experiments to analyze the kind of reasoning associated with either the acceptance or rejection of project proposals. An online recruitment system within a business school was used to randomly select and formulate six groups consisting of five members each. Six experimental sessions were dedicated to each five-member group and lasted approximately one hour each. Each participant played the role of a decision maker and spent 20 minutes individually reviewing seven project briefs. Next, the five participants engaged in five-minute group discussions regarding each project brief. Finally, participants voted either for or against each project with a show of hands.

Using descriptions of design reasoning worked out by Roozenburg (1993) as "innovative abduction" (p. 17) and by Dorst, (2011) as a combination of abductive reasoning and "frame creation as a core practice that is particular to the designing disciplines" (p. 531), the researchers developed a coding scheme to identify deductive, inductive, and abductive reasoning. The acceptance or rejection of project briefs was the dependent variable. A ratio count of abductive to deductive reasoning was used for a regression model and subsequent statistical analysis. Deductive reasoning positively correlated with project rejection, but abductive reasoning positively correlated with project acceptance. The authors concluded that all three forms of reasoning are involved in the design thinking process. The study results supported Dorst's, (2011) linking of abductive reasoning, design thinking, and reframing. Moreover, results supported Roozenburg's (1993) claim that the design process was characterized not by deductive reasoning but by "innovative abduction" (p. 18). Incidentally and according to Roozenburg, this characteristic of the design process made it resistant to computerization—while computers' could model deductive reasoning, they were unable to model abductive reasoning.

In short, when decision makers began to apply the design thinking cognitive strategy of innovative abduction during design concept selection, they departed from evaluation per se and began "design thinking." They invented new ways to frame the product as something other than as presented and explored new working principles to establish a new frame (Dong et al., 2015, p. 55). Abductive reasoning was described as an indicator of open-mindedness in project decisions and as tool decision makers can use to resist the premature closure of ideas.

Dorst (2011) explores the idea of framing and contends it is a "…special thing that design practices could bring to organizations that are struggling with open, complex problem situations…" (p. 527). Expert designers could use contextual information surrounding problems to reframe them in ways that suggest new ideas for achieving the desired value. Dorst provides an example of a music festival held in a section of a major metropolitan area for around 30,000 participants. Problems resulting from these congregations of revelers were initially framed as criminal behaviors that suggested the need for increased law enforcement.

The designers looked more carefully at the situation and hypothesized the causes for the increases in police reports of violent misbehavior. Crowd movement tended to stagnate due to a lack of local transportation and opportunities for focused attention just outside of the main entertainment venue. Borrowing strategies used by music festival coordinators, the designers generated ideas for occupying the attention of crowds outside of the main venues and for keeping people moving when their objective was to leave the area. The designers suggested ways of improving transportation and wayfinding and suggested smaller acts to be located outside the main venue. This kind of reframing of the problem led to lower reports of crime. Reframing allowed the underlying causes of the problems to be identified and addressed, whereas the initial proposal focused only on the symptoms of the problem and did not address the cause.

Design thinking is like other design theory in that it is somewhat fragmented because it is practiced and theorized in multiple domains. Johansson-Sköldberg, Woodilla, and Çetinkaya (2013) reviewed the design thinking literature and found a distinction between “designerly ways of thinking” and “design thinking.” “Designerly ways of thinking” was the scholarly strain of discourse, whereas “design thinking” was the business strain of discourse—and its authors made no effort to portray themselves as academics. Also, business and academic domains do work together. Both David Kelley and Tim Brown have welcomed academics to conduct research within the design firm, IDEO.

Within the academic domain of organizational creativity, for example, Amabile, Fisher, and Pillemer (2014) mapped the network of “helping relationships” (p. 57) within an IDEO office to explain how “collaborative generosity” (p. 55) was normalized within their organizational culture. They found the qualities of “trust” and “accessibility” more differentiating than that of “competence” when investigation what qualities make colleagues most helpful. Even if the discourse from designers in the business world makes little effort to frame itself within the scholarly literature, the writings and practices of design businesses are of high value to scholars of creativity and design.

Within the category of "designerly ways of thinking" Johansson-Sköldberg et al., (2013) identified five additional strains of discourse as displayed in Table 9.

Table 9

Five Strains of Design Thinking Discourse

Founder	Background	Epistemology	Core Concept
Simon	Economics and political science	Rationalism	The science of the artificial
Schön	Philosophy and music	Pragmatism	Reflection in action
Buchanan	Art history	Postmodernism	Wicked problems
Lawson and Cross	Design and architecture	Practice perspective	Designerly ways of knowing
Krippendorf	Philosophy and semantics	Hermeneutics	Creating meaning

Note: From "Design Thinking: Past, Present and Possible Futures." by U. Johansson-Sköldberg, J. Woodilla, and M. Çetinkaya, 2013, Creativity & Innovation Management, 22, p. 126. Copyright 2013 by John Wiley and Sons. Reprinted with permission.

This fragmentation is not surprising when considering the history of design theory and how it clusters and grows around different design practices. This fact contributes to design theory's eclectic character and accounts for some tension among the various domains of design practice regarding efforts to develop a unified theory of design. Konda, Monarch, Sargent, and Subrahmanian (1992) critiqued any moves toward the unification of design theory under the stewardship of a single domain "for not being more in accord with the social construction and shared memory perspective" (p. 5). They argued for a design theory that reflected the diverse array of those who use it, and the implications for design education were significant:

> The existence of disagreement in the legitimacy of particular methods in design (or in science) is often signaled by the phrase, "...you can't do that!" Innovative design often leads the development of analytical method, a designer with a deep appreciation of a subject can easily create a design for which there is no appropriate analysis but which nevertheless "feels right." Over-emphasis on analysis in the education of designers has a stultifying effect on their creativity – but this is already well-known. (Konda et al., 1992, p. 22)

However, the authors did suggest a use for an analytical specification. The utility of prescriptive models was noted in terms the affordances they offered stakeholders along administrative and managerial levels to have productive design conversations because prescriptive methodologies “enable effective sharing of meaning by making abstraction visible” (Konda et al., 1992, p. 25). Their primary argument was for an inclusive, integrative approach to the cultivation of design theory, “…it is a call to expand design research to include individual, organizational, and social elements which help designers collaborate by creating shared meaning, and maintaining it as shared memory” (Konda et al., 1992, p. 29).

This philosophical debate was extended by Love's (2002) framework which explored the question, “What characteristics would a coherent cross-disciplinary body of theory relating to designing and designs possess” (p. 346)? Humans, objects, and contexts were proposed as the essential elements of designing. The behaviors and interactions between those four elements were used to extend the idea to specific disciplines. Also, the need for clarity around definitions, core concepts, and terms for design was expressed. Four topical categories for framing definitions and core concepts of design were: 1) issues of cognition, 2) paradigms, 3) methodology, and 4) training and education. Issues of cognition included affect, values, ethics, and feelings.

Considerations of paradigm involved questions of compatibility between various epistemologies. Issues of methodology included the challenge of distinguishing between "designing" and other activities. Issues regarding training and education were posed as the questions, “On what theoretical basis are pedagogies and curricula of education for designers based? Are ‘competencies in designing’ defined across fields of design practice and associated domain knowledge areas? If so, how” (Love, 2002, p. 354)? This article aimed to lay a foundation and frame a discussion about an interdisciplinary theory of design. “The key element of this foundation is defining *designing* as ‘non-routine human activity that is an *essential* aspect of processes that lead to a design of an artefact.' This definition points to *designing* being a primary human function similar to *thinking* or *feeling*" (Love, 2002, p. 359).

Considering how dependent design is on its context, finding a unified theory of design seems counterintuitive and complicated. Also, eclecticism may be a healthy state for design theory so that diverse domains of practice are given voice and can cross-pollinate with one another. The transcontextuality of design may *be* a unifying theme. To complement the transcontextual nature of design, the recurrent patterns surrounding the design process can provide ballast for a design theory that is one part subjective and another part objective.

Nigel Cross was born in 1942 and has dedicated the full span of his career to the study of design (Cross, 1972, 2018a). As a way of summarizing design theory at the turn of the century, his review will provide guidance. Cross (1999) used quotations, comments, and sketches from expert designers to summarize findings in the literature about design and to approach the "value and relevance of research into artificial intelligence (AI) in design" (p. 25). His review resulted in the following summary. Design thinking is (a) rhetorical, (b) exploratory, (c) emergent, (d) opportunistic, (e) abductive, (f) reflective, (g) ambiguous, and (h) risky.

For Cross (1999) *rhetorical* means that design is meant to be persuasive. The *exploratory* nature of design means that design is not exclusively focused on optimally solving every problem but is more concerned with exploring problem spaces and surrounding contexts. Design ideas are *emergent*, that is they reveal themselves to designers as designers engaged with design work. Design ideas are not pre-specified and emerge in a dialectical way. Design is *abductive* when it requires designers to use intuition as a guide. This requires an abductive leap out of the given data and problem set. When design is *reflective*, designers contemplate their work using tools like sketches and writing to improve their design thinking. Designers must often create alternative solutions and leave solutions open during the design process, supporting the idea that design is *ambiguous*. Finally, design is *risky*. Expert designers acknowledge the element of risk with their work process.

There seems to be a need for designers to access the confidence they need to make risky design decisions that might lead to either innovation or failure. These design thinking qualities suggest the development of design thinking is contextually dependent as an interaction between context and designer.

Dorst and Cross (2001) used a think-aloud protocol with nine professional and experienced industrial designers to explore creativity in the design process. Participants were presented with a design problem and given 2.5 hours to provide a solution. Video cameras were used to capture the designers' gestures, sketching, and speech. A panel of expert judges was used to score the quality of the projects along the five dimensions of *ergonomics*, *technical aspects*, *aesthetics*, *business aspects*, and *creativity*. Scores from the expert judges showed a positive correlation between the dimensions of *creativity* and *project quality*. The researchers claim "Defining and framing the design problem is therefore a key aspect of creativity" (Dorst & Cross, 2001, p. 431). Results from the think-aloud protocol data showed all expert designers used a variety of strategies to define and frame the problem. Designers perceived the problem differently:

> The designer thus decides 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. The creativity of the design is thus influenced by all these factors. (Dorst & Cross, 2001, p. 432)

Researchers also found all designer participants used the information provided for the task to arrive at solutions they felt were highly original, when in fact all designers in the experiment arrived at the same design solution. Perhaps most interestingly, the researchers found that the fixing of the problem and the solution to not happen sequentially but interactively over time. Designers shift between both the problem and the solution spaces during the task process to ultimately create a matching problem/solution pair. According to the researchers, the creative event for designers occurs after the information is gathered and connected. Then, a surprising discrepancy between the designer’s idea of a “default solution” and the problem space.

> The recognition of the simplification happens suddenly, and is experienced as an idea (a creative insight). This finding of a coherence between the interesting information items apparently gives the designers the feeling of having grasped the core of the problem (‘the problem behind the assignment’). This is a highly emotional step, and none of the designers could ignore the impact. (Dorst & Cross, 2001, p. 436)

Findings from this research suggest that problem-finding and problem-solving “co-evolve” for designers and that a feeling of surprise can demarcate bursts of creative insight.

Interestingly, this element of surprise (or at least emotion) is echoed in Vygotsky’s earlier writings. Smagorinsky (2011) showed how Vygotsky emphasized imagination and emotion for development by highlighting a term Vygotsky began to use in the later stage of his career: *perezhivanie*. Vygotsky used this word "...to account for the central role of affect in framing and interpreting human experience" (p. 336). Smagorinsky further elaborated this experience of *perezhivanie*: "People frame and interpret their experiences through interdependent emotional and cognitive means, which in turn are related to the setting of new experiences" (p. 337).

Within the design experience, feelings of surprise or emotional excitement correlate with breakthrough moments in learning. Perhaps this excitement accounts for some of the fun ordinary folks seem to equate with design—or at least why designers like to design. Maybe these moments of surprise or excitement are universally felt experiences and surrounded by periods of the flow experience brought about by engrossing activities such as forms of play, the creative process of artists, or even the Japanese cultural phenomenon of Jujitsu-kan (Csikszentmihalyi & Asakawa, 2016).

Cross (1997) explored “the sudden insight provided by a ‘creative leap’ [which] is widely regarded as a characteristic feature of creative design” (p. 311). The “creative leap” has been recognized as part of the creative process for a long time. Recall Wallas' (1926) stage model of the creative process, which was based on his conversation with the physicist Hermann Helmholtz and the ideas of French mathematician Henri Poincare. This model consisted of the following stages of control: (a) preparation, (b) incubation, (c) illumination, and (d) verification. The preparation and verification stages involved full consciousness and attention. The incubation stage involved entirely unconscious thought. The illumination stage involved the “fringe” between incubation and illumination and was delicate. Creativity involved the ability to *let* things happen as opposed to *making* things happen.

When Cross says, "the sudden illumination that occurs in creative design is therefore more like building a 'creative bridge' than taking a creative leap" (p. 311), he is echoing Wallas' idea that illumination resulted in the interplay of unconscious and conscious states. Not that exploratory behavior is unconscious, but those exploratory behaviors are associated with an openness that is unhampered by a conscious focus on the problem. Creative design did not require a radical change in perspective but could also involve smaller shifts within the solution space. "This is what characterizes creative design as exploration, rather than search...creative design does not necessarily consist of the making of a sudden contrary proposal, but the making of an opposite proposal" (p. 311). Illumination, or the creative leap, is not something to be forced. Rather, it is something that designers are able to “let happen.”

To explore this phenomenon, Cross used an experimental method that involved creative designers working on a supplied problem for a couple of hours. The first breakthrough idea came one hour and eighteen minutes into the process, at which point all designers used the idea for formulating a proposed solution.

The team was aware that their work was part of experimental research and that they were being recorded. The team used a systematic approach to plan the creative process before working on the problem. Successive design phases were specified and given time limits. These design phases consisted of (a) exploring the problem and generating a performance spec, (b) generating multiple concepts, (c) evaluating and selecting from those options, (d) elaboration the selected concept, and (e) communicating the proposed solution.

At this point, the design team sub-divided the process according to the specific problem, which involved a way of attaching a backpack to a bicycle. The team conducted a series of cooperative thought experiments where they hypothesized various approaches and constraints. Nearly an hour and twenty minutes into the process a team member suggested the key idea at which point the other team members quickly reached consensus and based their design work on that key idea. This key concept was referred to by Cross as a "bridging concept between problem and solution that synthesizes and resolves a variety of goals and constraints" (p. 314).

Next, Cross discussed the example in terms of five established explanatory models of the creative design process. These models included analogy, combination, mutation, analogy, first principles, and emergence. A combination model involved combining existing features from two different designs, for example, combining a magnet and a screwdriver to produce a magnetic tipped screwdriver. A mutation model involved the modification of an existing product feature such as drilling holes in a large lade to produce a scoop that drains liquid. An analogy model involved design metaphors like the idea of plant burs in a dog's fur engendering the product of Velcro.

Another model of creative design involves the use of first principles, which "are fundamental facts or theories that supposedly, if followed rigorously, can lead to a functional solutions concept" (p. 316) This process involves decomposing the problem space into its non-reducible parts. From this position, a creative process begins and hopefully leads to a creative leap. "It is the abductive leap of reasoning from function to form that is regarded as the kernel of design" (p. 316). The quality of this leap depended on a deep understanding of the various components and the ability to apply the logic bound to each component within an abductive reasoning process that results in something new. For example, although bags and wheels are centuries old, it was not until the 1970s when Bernard Sadow reformulated their basic affordances as rolling suitcases.

An emergence model involved a process by which "new, previously unrecognized properties are perceived as laying within an existing design" (p 316). This ability to see potential solutions within a design scenario entails designers need to develop abilities of perception in order to recognize emergent behaviors and structures so that they can capitalize on them. An example of this might be city planners using *desire lines* or *paths* to construct paved walkways (*Chicago Area Transportation Study*, 1959; Lidwell, Holden, & Butler, 2010; Throgmorton & Eckstein, 2000).

Cross concluded with the observation that while most creative design models portrayed the design process as a linear sequence of stages, this linearity was not observed in his study.

> In practice, creative designing seems to proceed by oscillating between sub-solution and sub-problem areas, as well as be decomposing the problem and by combining sub-solutions… The appositional nature of design reasoning has been neglected in most descriptive models of the design process. (Cross, 1997, p. 317)

An alternative to considering design as sequential might be to consider the types of problems design is often used to address. Rather than a stepwise view of design activity, an appreciation of the various qualities of problems might inform understanding of the creative design process. For this avenue, the work of a scholar who devoted his career to the study of problem-solving will serve as a guide.

Problems and design. Jonassen (2011) identified 11 kinds of problems that varied according to five external characteristics. The characteristics of problems were: 1) structuredness, 2) context, 3) complexity, 4) dynamicity, and 5) domain specificity. Problems varied along a continuum of structuredness. There were the well-defined problems that supplied all the necessary information for a solution and had a single correct solution, like math word or algebra problems. These are the kinds of problems students typically encounter in school, often with a worked solution in the back of the textbook. Ill-structured problems were the authentic problems encountered in everyday life—problems that do not provide all the necessary information can be approached in multiple ways, and do not typically have a perfect solution.

Problems also varied according to context. Sometimes a simple, shallow context is supplied to frame the problem conveniently, like many story problems. For simple contexts, the context is irrelevant to problem-solving, and these kinds of problems might be called context independent. The most ill-structured problems have unclear, overlapping contexts. For these problems the context is deeply linked—maybe the problem would not even exist without the context.

For example, a lack of potable water for a small village being cut off from its last remaining supply by industrial development could pose a contextually dependent problem. These are heavily context-dependent problems, a characteristic of most design problems. The complexity of problems can also vary. Although well-structured problems are not usually complex, they can be. For example, a chess game is a well-structured, albeit complex, problem. There is nothing complex about being unexpectedly fired from a job, but it is an ill-structured problem.

Complexity itself varies along with internal and external factors. Internal complexity varies according to the breadth of knowledge required to solve the problem which includes the problem-solver's attainment level and domain knowledge. External complexity of problems varies along five factors: (a) the intricacy of problem-solution procedures, (b) relational complexity of domain concepts, (c) unknowns in the problems space (or intransparency), (d) the heterogeneity of how the problem is interpreted, and (e) the "interdisciplinarity, dynamicity, and legitimacy of alternative solutions" (Jonassen, 2011, p. 10).

The dynamicity of problems involves how the problem changes over time. The problem-solution space can change as the problem is being worked on, and the more dynamicity of problem has the more likely it is an ill-structured problem. Some problems have such a high degree of it that they morph into other problems while solutions are attempted.

Lastly, problems vary according to the domain and context specificity. A problem set in the context of a medical laboratory is different from a problem set in the context of political debate. Differences in domains and contexts mean that various problem-solving approaches only become appropriate according to the context and according to exactly how domain-specific a problem is. Working out a simple math problem is not context nor domain specific but negotiating a peace agreement between two warring factions is highly domain and context specific. Most design problems are domain and context specific.

Of all problem types design problems are some of the most ill-structured and variable as shown with Figure 7. Jonassen identified design problems as one of 11 kinds of problems that fall along a multi-leveled continuum with well-structured problems on one end and ill-structured problems on the other. Context-independent/dependent, high to low complexity, and dynamicity are used as additional dimensions to characterize different kinds of problems. The creativity literature suggests that problem-finding is complex, challenging, and possibly more important than problem-solving (Runco, 2004), and Jonassen noted that design problems are more challenging to identify than are well-structured problems. So, what are some of the strategies involved when facing design problems?

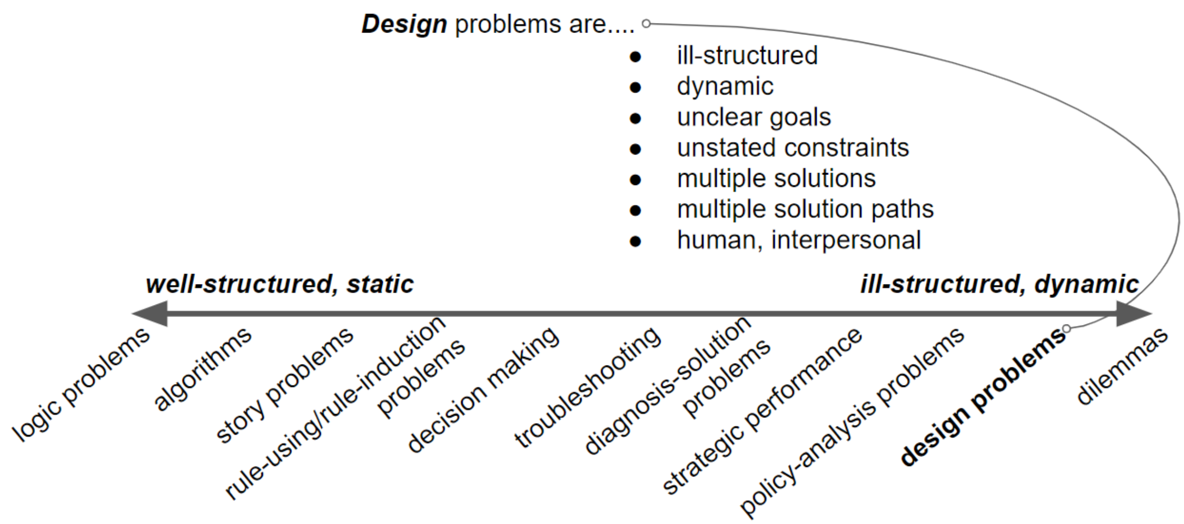

Figure 7. Problem types and their characteristics. Adapted from "Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments." by D. H. Jonassen, 2011, New York, Routledge.

According to Jonassen (2011), "Design is the most complex and ill-structured kind of problem-solving. Design is a ubiquitous professional activity" (p. 138). As we have seen, design theory literature exists within multiple academic domains and professional contexts. It is domain specific, and the underlying assumptions and goals for design vary according to the needs and interests of each group. The design literature has emerged from within four main areas: product design, architectural design, engineering design, and instructional design (Jonassen, 2011). Given the complexity and ill-structuredness of design problems it makes sense that "most disciplines attempt to define normative phase models for creating, constructing, and communication designs" (Jonassen, 2011, p. 139).

A systems design model used in a wide variety of educational contexts is the ADDIE model of instructional design. Instructional designers have used a systematic approach to improve the effectiveness of instruction. The ADDIE model (analysis, design, development, implementation, and evaluation) includes core elements/phases that are present in all systematic instructional design processes (Branch & Gustafson, 2007). These elements/phases are also recognizable in design phase models across multiple domains of design practice.

The hard versus soft systems methods of design discussed earlier were reflected in Hill and Hannafin's (2007) differentiation of the ADDIE model according to objectivist and constructivist epistemologies. Normative design models used across the disciplines of engineering design, product design, architectural design, and instructional design have all met with criticism. The rigorous and linear process of normative phase models constrained speed and flexibility. Also, the normative models were context neutral, whereas design problems depend heavily on their context. As Jonassen (2011) reminds us, “successful design must address the constraints imposed by the context, and those constraints emerge throughout the design process” (p. 146).

Jonassen recommended design problems be addressed using the following minimum guidelines: (a) the use of stories to convey design problems, an awareness of prior experiences and their potential for cognitive bias; (b) the use of case studies to gain experience and construct schemas for various types of design problems, (c) the use argumentation to justify design decisions, and (d) the use of modeling to represent the problem in a variety of ways with a variety of tools. Approaches to solving design problems were described in the following ways:

- the goal of design is satisficing, not optimizing;
- designers seldom perform all activities prescribed by normative design processes;
- design is an ill-structured, iterative process of model building;
- design decisions are responses to multiple constraints, not predefined rules;
- constraints are rarely identified upfront;
- design decisions are influenced by affective dispositions (Jonassen, 2011).

It was common for design models to emphasize problem finding as a starting point for the design process. The Design Council in London modeled the double diamond design process in 2004 (Design Council, 2007b). Their process model began with discovery and problem-finding phase before moving to the problem-solving phase. Both the problem-finding and problem-solving phases emphasized a mix of divergent and convergent thinking. Figure 8 is a simplified representation of the model.

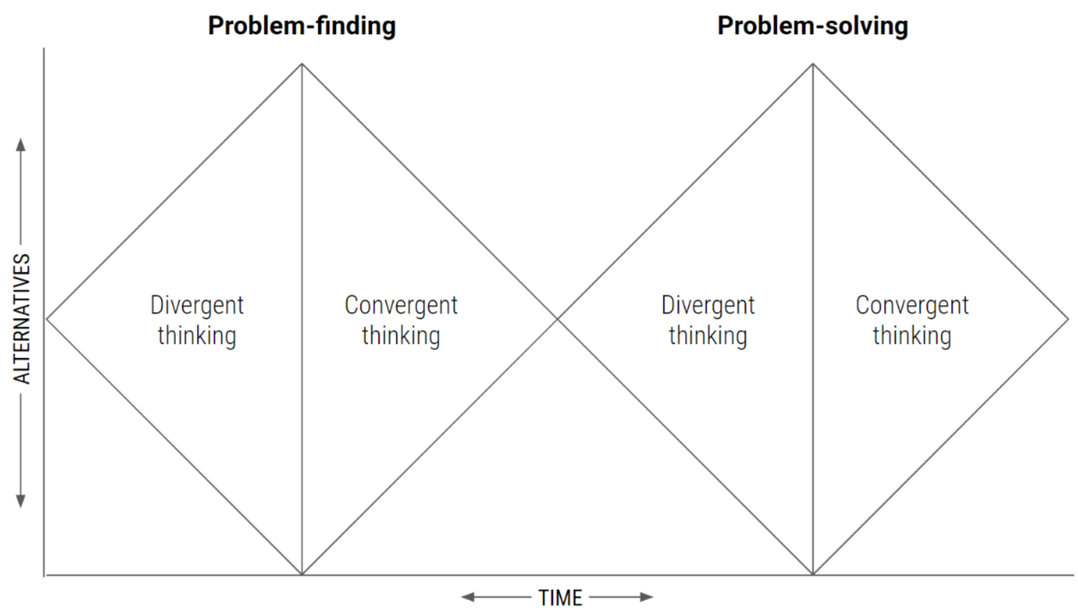

Figure 8. British Council double diamond model of design. Adapted from "What is the framework for innovation? Design council's evolved double diamond." by Design Council. Retrieved October 4, 2019, from Design Council website: https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond.

This generic design model is intended to be customized according to the context in which it was used, and each of the phases includes "…a series of iterative loops where exploration and testing of ideas can happen" (p. 10). Emphasis is placed upon the first phase, Discover, which is seen as the most critical phase because it is in this phase that the designer's knowledge and skills are most valuable. This first phase is the least defined of all the phases—"There is a level of ambiguity at this phase of the new product development process, and the process is largely unstructured" (p. 10). The first discovery phase is characterized by divergent thinking while the second phase, Define, is characterized by convergent thinking and culminates with an identification of the problem, the introduction of project management, and a project sign off (Design Council, 2007a). Once the problem is defined, the third phase begins the problem-solving component and involves developing and testing the proposed designs. The final quarter phase of the model, Deliver, is a delivery stage involving final approvals, product launching, feedback loops, and evaluation. The double diamond model was used as a framework for researching and reporting how eleven leading global companies used design processes.

Models and design. Models are used in many ways. Sometimes they are used in an epistemological sense to represent and communicate something about design and the design process. Other times they are used in a theoretical or phenomenological sense by designers as part of the design process. In the latter case, models are representations that mediate the design process. Models as mediating artifacts, both as physical tools and psychological signs have been described as fundamental to learning and development and as the crucial link between externalization and internalization of meaning (Vygotsky, 1978). Morrison and Morgan (1999) described models as "one of the critical instruments of modern science…as *autonomous agents*, and…as *instruments* of investigation" (p. 10). The inescapable theme running throughout all areas of design is the model.

The authors characterized models along the lines of (a) construction, (b) functioning, (c) representing, and (d) learning. The process of constructing models give models their autonomy, their independence from both theory and data. Because they are "in between" they are independent and occupy the lacuna between theory and practice. "It is because they are neither one thing nor the other, neither just theory nor data, but typically involve some of both (and often additional ‘outside’ elements), that they can mediate between theory and the world” (pp. 10-11). The autonomy of models is also bound to their variety of expression and their ability to function as tools and instruments that mediate many things. The tool is at once independent yet related to any given task, just as a hammer affords many applications.

Models also vary according to the degree of representation. As instruments, models can be dead simple, like a hammer. “We do not learn much from the hammer” (p. 11). However, models can also afford elaborate representations that turn them into tools of investigation. For example, a thermometer is a tool that provides information that can shape the investigation. A model might be an instrument that provides a simulation. A model might be an instrument that affords automatic, pre-programmed or computer-generated options for a creative design process.

This is the case with parametric design (Agirbas, 2018; Oxman, 2017) as applied in architecture, or other *metacreative* systems that provoke exploration and play within the design process (Bown & Brown, 2018). Interactive digital tools afford an elaborate degree of representation involving real-time feedback and multiple creative options. Designers can program and manipulate human-computer interfaces to dynamically generate, evaluate, and apply creative options—or even make use of machines programmed to think like people (Boden, 1998; Clark & Chalmers, 1998; Lake, Ullman, Tenenbaum, & Gershman, 2017). From the simple yet powerful combination of pencil and paper to Alan Kay’s *reactive engine* (aka Dynabook) to generative adversarial networks (Zhang et al., 2017)—models afford the designer a provocative variety of representation for investigation, exploration, and play.

Morrison and Morgan's (1999) fourth characterization of models is that of learning. The key to models and learning is in their use. Meaning is constructed through use in context— “the power of the model only becomes apparent in the context of its use…It is when we manipulate the model that these combined features enable us to learn how and why our interventions work” (p. 12). The authors subdivided use into two categories: constructing models and using models.

There are no set rules for the construction of models. Multiple modes of representation are useful for conceptual learning and are therefore appropriate for exploring design spaces:

> Well-developed mental models consist of multiple representations, including structural knowledge, procedural knowledge, reflective knowledge, images and metaphors of the system, of strategic knowledge as well as social/relational knowledge, conversational/discursive knowledge and artificial knowledge (Jonassen & Henning, 1999). The more ways that learners are able to represent problems in relation to disciplinary knowledge, the better able they will be to transfer their skills. (Jonassen, 2011, p. 309)

The activity of model construction blends theory and practice and represents it in an iterative, yet tangible, format. It is a process of "interpreting, conceptualizing and integrating" (Morrison & Morgan, 1999, p. 31). Put another way, the construction of models yields an "*object to think with,* Papert's idea of a turtle-like entity with which the user can relate" (Gargarian, 1996, p. 145). This leads to Morrison and Morgan's (1999) second part of learning with models: using models. If the construction of models helps to build ideas, the use of models helps to test them. "Models are not passive instruments, they must be put to work, used, or manipulated" (p. 32). Using models is a more public aspect of learning with them. When a model is used in this way it becomes a prototype.

Models are not limited to internal representations of knowledge, and prototypes provide ways to externalize that knowledge. "Proto" is derived From Greek prōtos 'first' and type is derived from Greek tupos 'impression, figure, type.' Usage of the term prototype can be traced to the late 16th century and was used to denote " the original of which something else is a copy or derivative." Writing from the field of software design, Gero (1990) said designers "schematize the knowledge" (p. 30) as generalized concepts in varying degrees of abstraction. Bartlett (1932) defined the term *schema* in this way, "'Schema' refers to an active organization of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response" (p. 201.) Schemas are internalized models of acquired knowledge. According to Gero (1990):

> A design prototype (Gero, 1987) is a conceptual schema for representing a class of elements derived from alike design cases that provides the basis for the start and continuation of a design. Design prototypes provide this basis by bringing all the requisite knowledge appropriate to the design situation together in one schema. (p. 31)

The prototype externally represents designers' knowledge about the situation at any one point in time. A high frequency and a wide variety of design prototypes can support the design process. Designers can generate prototypes with "any available information" (p. 33), and therefore design prototypes can be generated at any point in the design process.

Design prototypes could support *routine*, *innovative*, and *creative* design efforts. Routine design prototypes involved well-defined problems with all necessary information on hand at the outset of the design process. Innovative design prototypes involved the same well-defined state space but with unknown variables added. Creative design prototypes involved the generation of a prototype from scratch where context played a significant role in design decisions. According to this view, routine and innovative design prototypes might be approached in terms of design by various grains of a template, whereas creative design prototypes required a higher degree of originality and might be approached as a way of bringing entirely new ideas to the design process. A final recommendation was that design prototypes not be used to bring a rigid structure to the design process in general.

Technology has had a profound impact on modeling and prototyping. Parametric design thinking extends the power of designers with the aid of computerization. Oxman (2017) compared "selected cognitive concepts in both traditional paper-based models of design thinking and current computational models of parametric design" (p. 5) and extends the established theory of design thinking to parametric design thinking which involves the exploration of the problem and solutions space via programming. Parametric design expands traditional coding practices and allows designers to program tools to effect parameter changes in real time that allow them to explore the problem space via interactive interfaces. One analogy might be in sound design, where sound engineers and artists preprogram "macros" onto a tunable knob that in turn allows the designer to instantiate continuous changes to multiple parameters of their choosing with a knob, affording real-time instantaneous feedback to inform design decisions. Another analogy might be the sliders, knobs, faders, buttons, presets, and custom-programmed macros in digital graphics software that generate immediate feedback in response to designers' manipulation of the various inputs. "Design thinking in parametric design relies on tools that provide visualization of code and form of coded structure of the parametric schema and the 3D geometric model of the design object" (p. 21). Anyone who has adjusted sliders or pressed buttons to review their effects on graphics or audio has experienced a simple form of parametric design.

In architecture, this involves material design and fabrication. Parametric design in architecture allows "Contemporary process models such as formation, evolution, performance-based; and generative process models of design have been demonstrated as holistic processes of design thinking from conception to production" (p. 36). New programmable digital tools are becoming the norm in digital media design, and Oxman has related the concepts that have evolved with design thinking to new parametric control structures being uses within the field of architecture and material design. Some of the most exciting affordances of this new technology are the visual programming interfaces and immediate feedback they offer to designers as they explore problem and solution spaces.

Models, both psychological and instrumental, are the critical tools of creative design. This area will always be fertile ground for further study and exploration. Practically speaking, designers should explore and use a wide variety of models frequently and throughout the design process. In making thinking visible, models support the ascendancy from the abstract to the concrete, which is essential for sharing design ideas, design prototyping, reflection, and iteration.

Current trends and issues in design thinking. The following section on design will frame the modern strand of design thinking, its definition, and its application as a creative design strategy.

The term *design thinking* was initially associated with the fields of industrial design and education. Industrial designer, professor, and researcher Bruce Archer (Archer, 1963; Archer & Royal College of Art, 1970) used the phrase in his discussion of a proposed operational stage model of the design process. Archer taught design and researched at the Royal College of Art's Department of Design Research in London, where he was hired in 1961 to lead a research project involving the design of non-surgical hospital equipment (e.g., hospital bed). When reflecting on his career trajectory, Archer believed his efforts to fit design with management methods was off the mark, and *the most useful application of design would be its integration as the third broad category of an educational curriculum* comprised of the sciences, humanities, and design (Royal College of Art, 2016).

Writing for a *Design Studies* series on design and education, Cross (1982) borrowed Archer's (1979) "designerly ways of knowing" to frame his ideas for integration of design and education. This series was an effort to "establish the theoretical bases for treating design as a coherent discipline of study" (p. 221) and built upon the first two articles published by the journal, "Whatever became of design methodology?" and "The three Rs" by Archer (1979), who recommended design as "a fundamental aspect of education (in no sense a specialized subject) but that Design is (or should be) on a par with and distinct from science and the humanities" (p. 17). The *Design Studies* journal was launched on the premise that "Design can be identified as a subject in its own right, independent of the various areas in which it is applied to practical effect"

(p. 17). The capital "D" was intended to convey design's standing alongside the previously established pillars of education, Sciences, and Humanities.

Buchanan (1992) also used the term design thinking as he advocated for design as education. Kelley was another (Camacho, 2016). The historical associations of the term design thinking with design as education could be why the term is now regularly used to indicate an educational context for design. Interestingly, the recent mainstream popularity of design thinking was not initially sparked by the domain of education but by business and industry.

Writing from the field of product design, Brown (2008) used a few cases to describe design thinking and some qualities of design thinkers. These personal qualities were: (a) empathy, (b) integrative thinking, (c) optimism, (d) experimentalism, and (e) collaboration. (p. 3). For practice, a system of "spaces" for engaging in design thinking (i.e., project work) was proposed: (a) inspiration, (b) ideation, and (c) implementation. (p. 5). Brown's concise description of the design process was a jolt, especially in comparison with the musings found in so many academic journals.

1. Begin at the beginning;
2. Take a human-centered approach;
3. Try early and often;
4. Seek outside help;
5. Blend big and small projects;
6. Budget to the pace of innovation;
7. Design for the cycle (p. 8).

Writing from the business strain of discourse on design, Brown used Edison as a prototypical example of a design thinker. What set Edison apart from other inventors was that he conceived a fully developed marketplace for his inventions as opposed to a focus on the invention only. Edison's crucial contribution was not necessarily the lightbulb or any single invention, but "the modern R&D laboratory and methods of experimental investigation" (p. 1). Edison made innovation "a profession that blended art, craft, science, business savvy, and an astute understanding of customers and markets" (p.1).

Brown defined design thinking as a methodology for innovation for businesses, calling design thinking "a methodology that imbues the full spectrum of innovation activities with a human-centered design ethos" (p.1). Moreover, "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity" (p. 1). Brown portrayed design thinking as a collection of methods oriented toward increased innovation within the world of business.

For Brown, the context for design thinking was framed by the market, by capitalism. As Dilnot (1984) noted, design as a practice moved from a craft activity to a tool of industry and after 1945, in America especially, design was more and more framed by capitalism and pop culture. At the time of its writing, Dilnot (1984) could scarcely have imagined the effect Apple's release of the Mcintosh computer would have on the world of design. Brown was CEO for IDEO, a design company that did work for Apple and credited with designing the first mouse Apple used for its highly successful line of Mcintosh personal computers. Brown's (2008) article on design thinking shared the design philosophy that was at least partially responsible for the widespread adoption of pioneering technology that brought the power of computerization into mainstream America.

Brown explained how design had become more than a surface treatment. Instead of designing for style, design was applied to understanding and meeting customer's "needs and desires" (p. 2). Also, design was going beyond the physical product and into the design of new processes and experiences. With this shift, the psychology of design became of interest, as was shown by the popular book from Don Norman, *The Design of Everyday Things*, which was originally titled, *The Psychology of Everyday Things*. Design and designers began to seriously focus on people's experiences as users of products and this interest manifested in a raft of methods aimed at understanding human experience.

For example, a design team tasked with improving the quality of patient and practitioner experience in a hospital setting began by embedding themselves in the daily routines at the hospital. After careful observation and collaboration with employees at the hospital (design thinking suggests many methods for doing this kind of research), the team identified core problems and used rapid prototyping methods to explore possible solutions.

The concept of empathy was the conceptual underpinning for the design practice of design thinking. Kouprie and Visser (2009) proposed a framework for empathy in design based upon findings in psychology. They noted the construct of empathy "originated in 1873 in art history, when Vischer used the term 'Einfühlung' (German for feeling into) to describe a process in which a woman projects her entire personality upon an object, and in some sense merges with this object" (p. 441). They traced the development of empathy as a psychological construct and concluded that "stepping into and stepping out of the user's world are important phases to distinguish and achieve" (p. 444) and operationalized empathy as the four phases of *discovery*, *immersion, connection*, and *detachment*. (Kouprie & Visser, 2009) suggested designers should (a) be motivated to practice empathy, (b) be flexible enough to cycle between the phases of immersion and detachment, and be willing to invest and structure their time to include all four phases of empathic design.

Prototyping was another area where design thinking methodology was innovative. As opposed to the elaborate prototyping methods used by previous generations of designers, rapid prototyping was a quick and disposable process embedded throughout the design process, "Prototypes should command only as much time, effort, and investment as are needed to generate useful feedback and evolve an idea" (p. 3). A whatever works strategy seemed applicable to prototyping, and it is possible the most mundane, yet useful tools could be overlooked. Rieber, Barbour, Thomas, and Rauscher, (2008) recommended PowerPoint as an accessible and easy to use prototyping tool. This approach to prototyping emphasized simple and agile prototypes overelaborate and complicated prototypes that could sometimes have the unintended effect of bogging down the design process. Brown promoted prototypes as quick and easy ways to communicate and iterate design ideas.

Ultimately, the design team delivered a "portfolio of innovations" which was so effective that the client, Kaiser Permanente, created its innovation center based on these design thinking methods. Recall Horst Rittel spent much of his career theorizing the problem of "wicked" problems and suggesting solutions but was unable to move the field much beyond the methods he helped introduce to the design world in 1963. Brown and his team at IDEO were pushing past old limitations and do something that satisfactorily addressed "wicked" problems—the kinds of problems that were discussed by Jonassen (2011) as ill-structured, contextual-specific, complex, dynamic, and domain-specific problems. Design problems have these qualities in higher degrees than any other problem type, and Brown’s philosophy of action seemed to achieve better results than Rittel’s philosophy of analysis.

So, what else was it about design thinking that made it more effective than earlier design approaches? For Brown, success was the result of "hard work augmented by a creative human-centered discovery process and followed by iterative cycles of prototyping, testing, and refinement" (p. 4). Brown was quick to point out these components should not be thought about in terms of "a predefined series of orderly steps" (p. 3) but instead as a "system of spaces" (p. 3).

The lack of a conventionally conceived design process allowed the design problem to remain open throughout much of the design process before converging on a solution. The idea of the "problem" was expanded to include the idea of "opportunity" so that research might have the chance to offer solution paths characterized more by abductive logic than deductive or inductive thinking. The inspiration space motivated the search for solutions. The ideation space involved generating, developing, and testing ideas. The implementation space was for figuring out how to bring the product to market.

Throughout the process, a human-centered exploration guided the designers. This human-centered, flexible approach to design, along with a collection of specific methods centered around observation and prototyping, characterized the design thinking process. Nothing about the design process was complicated or difficult to understand. The difference that made a difference was in the reframing of the design process and the attitudes of the designers. The difference was in actions and attitudes.

The design process was complemented with a systems view that encouraged designers to zoom out to see the full context and how the product, process, or idea related to socio-cultural, economic, and historical contexts. An understanding of the constraints and affordances of the larger system was used to focus efforts to innovate in the right places. Brown used the case of a company looking to reduce the cost of eyewear for poverty-stricken people in rural, remote areas. A systems analysis led to a move that resulted in eyewear manufacturing in situ rather than using the conventional supply-chain method of delivery, which resulted in a feasible cost and quality outcomes for these people--"a systemic solution to a complex social and medical problem" (p. 7).

Brown's design perspective is from the business of product design and not engineering, education, or purely academic theory. Therefore, there are information gaps regarding the assessment, the training, and the theorization of design. Also, Brown's insight into the practice of design has the interesting effect of cleaving the overall design conversation neatly into piles of practice and theory. For those interested in design as education, the appeal of a clearly outlined design methodology is a welcome relief from circular theoretical tomes. If anything, it is a human-centered approach to reporting the nature and practice of design. Perhaps Brown's concise yet well-rounded discussion of design has something to do with the popular adoption of design thinking methods.

Similar to Brown's (2008) idea of leaving the design process open as a "system of spaces," Wylant (2008) placed value on entertaining multiple ideas within the design process.

> That one entertains a placement is indicative of the playful quality inherent in the design pursuit. Given the curiosity that drives such play, and the skill with which it is executed, an effectively broad range of issues can be raised and duly considered in the development and introduction of innovative new things" (p. 14).

A series of rough sketches beginning early in the design process could serve to entertain design placements without a firm commitment. "Even within the completion of a single sketch there are aspects of preparation, validation, and outcome, and so the completion of any interim step can be seen as an execution of the larger creative process in miniature" (p. 12). Design thinking transformed the idea of the prototype from something fastidiously wrought to something quick, disposable, and sharable.

Sketches were easy and cheap—they moved ideas along without the bog of elaborate pre-specification. They represented an approach to prototyping that pushed back against the habit of creating elaborate prototypes in painstaking detail. "Based on his firm's client experiences, David Kelley that organizations intending to be more innovative need to move from *specification-driven prototypes* to *prototype-driven specification*" (Schrage, 1996, p. 195). There were no hard rules for prototyping save for the ideas that prototypes should be done quickly, cheaply, periodically, and not seen as the "property" of any single person. Prototype-driven innovation provided "Schön's *backtalk* to the designers, and also can serve as an essential medium for information, interaction, integration, and collaboration. – Terry Winograd" (Schrage, 1996, p. 192). Prototypes are a form of modeling the problem and "modeling is key to the design enterprise" (Jonassen, 2011, p. 148).

David Kelley is a founder of the international consulting and design firm IDEO, and Tim Brown is the CEO. Their success stories and books (Brown, 2009; Kelley & Kelley, 2013) have helped promote the ideas of design thinking in popular culture and IDEO's partnership with the well-funded and privately held educational institutions of Stanford University in the United States and the Hasso Plattner Institute in Potsdam, Germany has yielded much research into design and design thinking for education.

IDEO's (n.d.) website provides another model for design thinking. (Don Norman recommends it: http://designthinkingforeducators.com). The "five phases" of the design process are listed on their web site. Design thinking was is described as a mindset and "the confidence that everyone can be part of creating a more desirable future, and a process to take action when faced with a difficult challenge." The site includes resources for educator's so that they can try design thinking out in classrooms. The five phases are preceded by the description, "The design process is what puts Design Thinking into action. It's a structured approach to generating and developing ideas,"

1. *Discovery* - I have a challenge. How do I approach it?
2. *Interpretation* - I learned something. How do I interpret it?
3. *Ideation* - I see an opportunity. What do I create?
4. *Experimentation* - I have an idea. How do I build it?
5. *Evolution* - I tried something. How do I evolve it?

Stanford's d.school, along with design firm IDEO and Tim Brown's writings, have suggested the design community to "…think beyond both the omnipotent designer and the obsession with products, objects, and things" (Bjögvinsson, Ehn, & Hillgren, 2012, p. 101). Their design methodology was characterized by a humancentric design approach emphasizing socially contextualized design, collaborative design, and prototype design. "HCD (human-centered design) methods have consistently emphasized user feedback and advocate that design teams work with the user to design products that are more in line with the user’s needs”(Menold, Jablokow, & Simpson, 2017, p. 91).

One strength of d.school design thinking model might be in its uncomplicated presentation. The simplicity is a stark contrast to many of the design models found in academic journals (Wynn & Clarkson, 2018). The d.school model consists of the five action verbs *empathize*, *define*, *ideate*, *prototype*, and *test* and is sometimes presented with a clear, easy to grasp graphic as reproduced in figure 10 below. Carter, Bababekov, and Majmudar (2018) use the graphic as part of their article in *Nature* to communicate a human-centered design approach for graduate medical education.

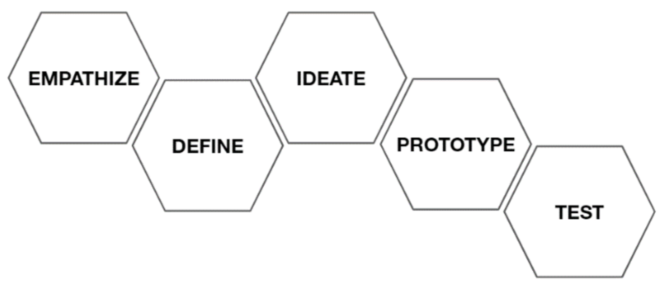

Figure 9. Stanford d.school design thinking model. From "Design Thinking Bootcamp Bootleg." by Hasso Plattner Institute of Design at Stanford University. Retrieved October 26, 2018, from Stanford d.school website: https://dschool.stanford.edu/resources/the-bootcamp-bootleg. Reprinted with Creative Commons attribution-noncommercial-sharealike 4.0 international license.

Is it obvious that this representation of design thinking is an oversimplification of the design process? A literal interpretation of the model would be misleading and potentially interfere with students’ initial development of creative schemas. *Explicitly stating this problem is important*. All models are wrong, and some are more useful than others (Box & Draper, 1987).

This graphically appealing model functions as a mnemonic device or memory device. Within each hexagon are collections of contextually dependent psychological and technical design methods. Throughout all, a set of attitudes guide action. Overall, a human-centered orientation provides the object for design activity.

Zidulka and Mitchell (2018) discussed how the “instrumentally focused definition of creativity within DT classes might lead to the unwitting marginalization of other forms of creativity” (p. 757). This problem echoes throughout the creativity literature: "The major challenge with creativity has been resistance to change by organizational members (Amabile, 1998; Hon, Bloom & Crant, 2014) as they fail to comprehend an organized process of implementing the creative ideas" (Brown & Kuratko, 2015, pp. 147-148). There are tensions and contradictions between the objectives to market design thinking as a quick and appealing commodity and to provide an authentic, messy, time-consuming experience with creative design. One way of conceptualizing the contradiction might be the comparison of eating at a fast-food restaurant with growing food in a garden.

Although there are times when the map *is* the territory (Siegert, 2011), e.g., virtual reality and immersive art experiences, the models of design or design thinking under review are imperfect representations of design and design process. Korzybski's (1931) famous quote, “A map *is not* the territory” (p. 750) applies to current and past models of the design process. As a theorist and teacher within the field of semantics, Korzybski sought to free students of their old dogmas through interventions that facilitated a questioning of assumptions (Pula, 1991). This is something that design thinking attempts to accomplish as well. Preferences to either take the model at face value or abstract it may have much to do with the differences Kelley described earlier between engineers and creative designers. This distinction may be challenging and cause discomfort to those people most comfortable with rational or concrete thinking (Förster, Friedman, & Liberman, 2004; Kirkpatrick & Epstein, 1992; Pacini & Epstein, 1999). This area of research should be further investigated!

Writing from the field of education and specifically the d.school, Rauth, Köppen, Jobst, and Meinel (2010) summarized the basic principles of design thinking education as reprinted in Table 10.

Table 10

Basic Principles of Design Thinking Education

Principle	Description
Human-centered	Design thinking is a human-centered process. The focus is on making people the source of inspiration and direction for solving design challenges.
Mindful of Process	A critical mindset in design thinking is being “mindful of process” or having metacognitive awareness.
Empathy	Empathy is the intellectual identification with or vicarious experiencing of the feelings, thoughts or attitudes of others. Empathy develops through a process 'needfinding' in which one focuses on discovering peoples’ explicit and implicit needs.
Culture of Prototyping	The mindset of creating and maintaining a “culture of prototyping” focuses on being highly experimental, building to think, and engaging people with artifacts.
Show Don't Tell	As a mindset, “show don't tell” takes traditional visualization one step further, as it includes sketching and traditional prototyping, digital communication and storytelling.
Bias Toward Action	Bias Toward Action is a focus on action-oriented behavior rather than discussion-based work. A “bias toward action” mindset utilizes all modalities of learning.
Radical Collaboration	This mindset is built upon the idea that radically diverse multidisciplinary teams will lead to greater innovations than teams that come from the same discipline. Examining and confronting team dynamics is an essential component.

Note: Reprinted from "Design Thinking: An Educational Model Towards Creative Confidence." by I. Rauth, E. Köppen, B. Jobst, and C. Meinel, 2010, Proceedings of the 1st International Conference on Design Creativity, p. 3. Copyright 2010 by The Design Society.

These principles emphasized a human-centered design approach, prototyping, and collaboration.

Table 11 is reproduced from Stanford’s d.school website and provided a recent update.

Table 11

Eight Core Design Thinking Abilities Taught at the d.School

Design thinking ability	Description
Navigate Ambiguity	This is the ability to recognize and persist in the discomfort of not knowing and develop tactics to overcome ambiguity when needed.
Learn from Others (People and Contexts)	This means empathizing with and embracing diverse viewpoints, testing new ideas with others, and observing and learning from unfamiliar contexts.
Synthesize Information	This is the ability to make sense of information and find insight and opportunity within.
Experiment Rapidly	This ability is about being able to quickly generate ideas – whether written, drawn, or built.
Move Between Concrete and Abstract	This ability involves understanding stakeholders and purpose in order to define the product or service's features.
Build and Craft Intentionally	This ability is about thoughtful construction: showing work at the most appropriate level of resolution for the audience and feedback desired.
Communicate Deliberately	This is the ability to form, capture, and relate stories, ideas, concepts, reflections, and learnings to the appropriate audiences.
Design your Design Work	This meta ability is about recognizing a project as a design problem and then deciding on the people, tools, techniques, and processes needed to tackle it.

Note: From " 8 core abilities." by Hasso Plattner Institute of Design at Stanford University, 2019, from Stanford d.school website: https://dschool.stanford.edu/about/#about-8-core-abilities. Copyright 2019 by Hasso Plattner Institute of Design at Stanford University. Reprinted with permission under Creative Commons license.

Table 11 above included *navigate ambiguity*, an idea derived from ambiguity tolerance (Frenkel-Brunswik, 1949; Furnham, 1994; Macdonald, 1970; Zenasni et al., 2008). Newly added verbs indicate various forms of agency and metacognition about the design process which include awareness of design projects as design problems and awareness of prototype fidelity as a function of communicating design ideas. This is closely connected with some concepts introduced by the team of programmers responsible for the agile manifesto ("Manifesto for Agile Software Development," 2001). Rapid prototyping can be traced to (Beck, 1999) and the "agile manifesto" of software design which emphasized speed, autonomy, and quality. Two of the 12 statements from the manifesto are listed below.

1. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference for the shorter timescale.
2. Simplicity—the art of maximizing the amount of work not done—is essential.

As Kelly discussed earlier in this section, in design thinking, prototypes are meant to be easy and sharable as opposed to elaborate and one person's property. The ideas of (Beck & Cunningham, 1989) that led to the agile manifesto have been influential beyond the world of software design. The agile manifesto provides a good example of theory derived purely from practice and not specialists in theory. Both design thinking and agile methods emphasize communication design ideas throughout the process as both a way of iterating prototypes and as a way of convincing other stakeholders that an idea is valuable.

Communicating ideas relates to Cross's (1999) characterization of design as rhetorical. Whether within a design team or when communicating with clients, there is always an element of persuasiveness needed when sharing or "selling" a design idea. Cross used an example taken from Simon's book, *The Sciences of the Artificial* (1969) to convey this aspect of professional-client relations. Simon asked architect Mies van der Rohe how he found the opportunity to build a "startlingly modern" home in the Netherlands.

> Wasn't the client shocked," I asked, "when you put before him your glass and metal design?" "Yes," said Mies, viewing the tip of his cigar reflectively, "he wasn't very happy at first. But then we smoked some good cigars, . . . and we drank some glasses of a good Rhein wine, . . . and then he began to like it very much. (Simon, 1969, p. 151)

This episode reflects persuasion, but not much in the way of rhetoric. In fact, if van der Rohe had engaged in rhetoric, the contract may not have been extended. Rhetorical arguments are one of the most common forms of argumentation, and a commonly used model is Toulmin's (1958), which involved one person using data to back up claims using warrants. But this idealized model is one-sided and does not account for multi-voicedness *or* for multiple arguments (Driver, Newton, & Osborne, 2000).

The family of dialectic arguments, however, does account for multiple perspectives. A middle ground is often sought, where the aim is toward a resolution between all parties rather than one side “winning” over the other. Some designers may get their ideas accepted via a rhetorical argument, but other times may reach consensus via a dialectic process. It’s difficult to tell what exactly persuaded van der Rohe’s client, but it seems reasonable that the soft approach was more effective than pushy rhetoric might have been.

From 2008 on, design thinking gained in popularity. Stanford’s d.school initiative was well funded and continued to garner attention from the business and educational communities. The year 2013 was an active year for design thinking in mainstream publications. David and Tom Kelley published, *Creative Confidence* (2013) which included practical application tools along with the main narrative accounts of design and design thinking as experienced by professional designers. Don Norman’s popular book, *The Design of Everyday Things* (2013), was revised, expanded, and republished to include two new chapters: Design thinking and Design in the world of business.

As the term design thinking gained popularity, some teachers gave design thinking a test in K-12 environments. One teacher observed that design thinking might not work well for K-12 students:

> I suggest that teaching this process to K-12 students is not only unfeasible, but unnecessary and limiting. Rather than spending time teaching a structured, cookie-cutter problem-solving process, time might be better spent teaching, and facilitating learning in a breadth of subjects. Rather than give students more structure, they may benefit from less, yet more learning. To think outside of the box, to have multiple perspectives, students require an education grounded in the humanities. (Morrison, 2013)

But a “structured, cookie-cutter problem-solving process” was *exactly* what design thinking, at least according to Kelley (2013) and Brown (2008; 2009), was *not* supposed to be. Everything about this characterization of design thinking methods is wrong. My hunch is the graphic models typically used to communicate design thinking methods do more harm than good.

Although the step or phase-oriented models were intended to function more as mnemonic devices that a stepwise linear recipe, they do convey a normative model of instruction. It is easy to see how these kinds of misunderstandings occur, and it is probably wise to not lean heavily on the use of these kinds of graphics when introducing the concept to students or instructors. Learners’ initial schema development and efforts to improve design thinking methods based on critique are stalled by these kinds of misunderstandings. To be fair, it is difficult to resist using the aesthetically pleasing graphics of design thinking that are easily located online.

As a counterpoint to a simplistic representation of design thinking it may be valuable to approach design thinking from a competencies perspective. Razzouk and Shute (2012) described design thinking with the three categories of (a) theory, (b) personal traits, and (c) process. Their model focused on conceptual maps of design, theoretical definitions, and process descriptions. The personal traits category included human- and environment centered concern, ability to visualize, flexibility, systems thinking, collaboration, communication of design ideas, and divergent thinking abilities. Their process component was described as iterative and characterized by different phases or sequences of specific cognitive activities such as *preparation*, *assimilation*, and *strategic control* (p. 337). Their hypothesis is that if aspiring design thinkers accumulate experience with these aspects of design thinking, they will advance as designers and become incrementally more expert with experience.

Razzouk and Shute (2012) conducted a review of the design thinking literature and developed a design thinking competency model. Their hierarchical model operationalizes design thinking into three categories: design thinking (a) skills, (b) terminologies, and (c) behaviors.

These categories were further refined, resulting in twenty-six nodes to represent discrete behaviors associated with design thinking. The authors suggested that the more of these behaviors designers develop, the further along the novice-expert design thinking continuum they should advance. A comparison of novice and expert designers resulted in two observations:

1. Novice designers tend to approach problems in a depth-first way, whereas expert designers tend to approach problems in a breadth-first way, emphasizing context and interconnectedness.
2. Expert designers tend to be flexible and work with changing goals and constraints.

The researchers' *design thinking competency model* might be used to track the development of design thinking in aspiring designers. This model might also be used to shape the design of instructional interventions aimed at the development of design thinking in students.

In collaboration with Stanford's d. school, Royalty et al., (2012) conducted research into design thinking education to develop a model of "creative competence" (p. 95). Their working definition of design thinking and the qualities of design thinkers was derived from Brown (2008) who outlined 1) inspiration, 2) ideation, and 3) implementation as three design spaces and defined the "Characteristics of design thinkers, according to Brown, include empathy (taking others' perspectives), integrative rather than solely analytical thinking, optimism, experimentalism, and seeking collaboration." (Royalty et al., 2012, p. 96).

For this educational context, the learning goals of design thinking education were defined as "developing creative intelligence or competence, including skills, confidence, and performance in relation to real-world problems." (p. 96).

A literature review was used to formulate a conceptual model comprised of four states for the development of design thinking. *Methods* included intellectual ability including knowledge as described by Sternberg (2006) and the skills and processes of design thinking as described by (Rauth et al., 2010). *Dispositions* involved motivation as described by Sternberg (2006), creative confidence as described by (Rauth et al., 2010) and Tierney and Farmer's (2002) description of creative self-efficacy, and Brown's (2008) experimentalism as interpreted to be risk-taking behaviors.

These first two levels involved design thinking practice by students. The last two levels involved design thinking as practiced by professionals. *Application* involved practice with design thinking methods and dispositions. *Adaptation* involved "going beyond what was learned and using design thinking knowledge and capacity in novel and unexpected ways" (p. 97) which involved using design thinking outside of the school context and in professional domains.

The study used a mixed methods approach involving online questionnaires and follow-up interviews to find if the design thinking skills and mindsets had been learned and to explore unexpected outcomes. The initial survey invitation was emailed to 670 d.school alumni who had completed graduate studies in a variety of areas. Of these, 16 participants were selected to participate in interviews that were either in-person or conducted online via Skype.

The survey questions and subsequent interviews probed for information regarding design thinking methods and dispositions. These categories were: (a) Defining/re-framing, (b) Brainstorming/ideating, (c) Empathy – prototyping, (d) Teamwork/Collaboration, (e) Creative confidence, (f) Bias towards action, and (g) Comfort with uncertainty/failure.

Many of the participants reported having developed creative environments in both their work and personal lives. This included the participants teaching their friends and co-workers "elements of design" (p. 102). The survey results showed the most frequently referenced skill or methods-based outcomes to be "empathy for users/clients, brainstorming/ideating, and prototyping/iterating; alumni also reported applying what they learned about inter-disciplinary teamwork in their professional lives" (p. 103).

The next step for this research was to generate new categories based on the collected survey data. These new categories were (a) confidence to develop a creative environment, (b) comfort with ambiguity, and (c) "how actively one is continuing to develop a creative process" (p. 103). Then, those categories were used to develop a "creative confidence self-efficacy" assessment instrument that involved testing with available and active d.school students.

Continuing with the d.school setting, Royalty, Oishi, and Roth (2014) worked from "a common pedagogy that focuses on an overall process with five core constructs: Empathy, Define, Ideate, Prototype and Test" (p. 81). The researchers looked beyond these constructs to measure "attitudes and dispositions that propel them toward creative activity and achievement" (p. 81). In need of a term that "reflected the multifarious nature of the creative competencies that many d.school graduates exhibited " (p. 82), the researchers derived a term from the multiple constructs of agency (Bandura, 2006), self-efficacy (Bandura, 1982), and creative self-efficacy (Tierney & Farmer, 2002). "We defined creative agency as individuals' capacity to effect change in themselves and their situations to support successful creative problem-solving" (p. 82).

An online survey was administered to 184 d.school graduate alumni. The collected data was then analyzed and coded using six a priori categories and post hoc categories: (a) Empathy, (b) Define, (c) Ideate, (d) Prototype/test, (e) Teamwork, (f) Creative confidence, (g) Comfort with risk, ambiguity, change, or failure; (h) and Bias towards action. Of these the most frequently referenced categories found in the survey response data were empathy, ideation, and prototyping. Further analysis of the survey and interview data led to 11 inductively derived "key competencies frequently demonstrated by successful alumni" (p. 89). These competencies were:

1. Sources (gathering information from external sources);
2. Comfort (with ambiguity);
3. Mastery (of one's own creative process);
4. Environment (developing creative environments);
5. Anti-perfectionism (reducing a sense that everything must be perfect);
6. Prototyping (developing a culture of prototyping);

7. Perseverance (increased in the face of failure);
8. Facilitation (confidence to lead a creative process);
9. Openness (to changes in thought, direction, beliefs, et cetera);
10. Process (being able to describe one's own creative process);
11. Creative Output (solving problems in creative ways). (Royalty et al., 2014, p. 89)

These results were used to formulate an initial model of creative outcomes. These outcomes were distributed along a continuum ranging from "internal" to "external." Outcomes at the internal end of the continuum were:

1. Creative self-efficacy: Belief in one's creative abilities
2. Creative agency: Applying one's creative abilities

Outcomes at the external end of the continuum were:

1. Creative output: Manifestations of applying creative ability
2. Creative impact: Effects of creative actions (p. 93)

Their new model was comprised of four constructs relating to creativity that were distributed as either internal or external along a continuum with a range that included self-efficacy, agency, output, and impact.

The instrument used to gather the related data was called the *Competency-based Creative Agency scale*. Further research was planned to gather psychometrics regarding instrument validity and reliability with an eventual goal to "expand the research to its potential predictive validity, its neurological correlates, and ways to use it in controlled experiments" (p. 95).

Royalty and Roth (2016) worked to develop a survey instrument to assess design thinking by operationalizing design thinking via the four categories of *empathy*, *reframing*, *iteration*, and *team collaboration*. Again, note the similarity of these categories to the categories and survey items discussed previously (Blizzard et al., 2017; Brown, 2008). Royalty (2016) call their instrument a measure of *creative agency*. The construct of creative agency was derived from Bandura's (1977, 1982) construct of *self-efficacy* and Dweck's (2006) construct of *creative growth mindset*. Royalty and Roth (2016) combined these two strands of research to account for a combination of confidence (self-efficacy) and creativity (open mindsets) they saw as characteristic of design thinking. Their assessment instrument consists of 11 five-point Likert items for the creative agency scale and three six-point Likert items on the creative growth mindset scale.

In this exploratory study, Royalty and Roth (2016) observed and participated in the meetings of four different companies that were at different stages of integrating design thinking methods into their corporate culture. In addition, researchers conducted eight interviews with employees from different levels of management with seven different companies. Open coding of the interview data resulted in the four categories which were described in terms of design thinking from the multiple perspectives of people, projects, programs, and unknowns. Using a framework derived from Amabile (1996) the researchers formulated an ecology mapping of three components for each organization. The components were (a) innovation target, (b) design activities, and (c) employee training profile. Innovation target mappings occurred along an x-y axis.

Cost saving and revenue generating were mapped along the x-axis. Incremental and radical change were mapped along the y-axis. Design activities were charted using a spider diagram. The number of design thinking trainings vs. the number of design thinking experts were mapped along one dimension. The percentage of organization trained, and the number of design thinking projects were mapped along the perpendicular dimension. The employee training profile was charted along an x-y axis. The x-axis contained categorical bins for the three management levels of early career, middle management, and senior leaders. The y-axis was used to indicate the level of training. These ecology mappings of innovation target, design activities, and employee training profile corresponded with Amabile’s (1996) components of management, resources, and motivation, respectively.

The study was ongoing. A few examples of the ecology mappings demonstrated how they could represent relationships between design thinking activities, innovation, revenues, and employee training between different companies and within the same company across time.

Study 2: Measuring Team Behaviors and Outcomes

“defining behaviors as actions taken that support design thinking methods and mindsets” (p. 41)

“Csikszentmihalyi captured subjects actions and “random” times by paging them and having them capture what they were doing (Csikszentmihalyi and Larson 1987). This contributed to his theory of flow. Another study by Amabile measured creative activities employees performed via daily journals (Amabile et al. 2005). (p. 41)

The research site was a 10-month leadership program for 30 middle managers who had been identified as future leaders within a company. These employees were expected to spend about 15% of their time using “design thinking to tackle an ambiguous problem specifically outside their skill set, i.e., make the hospital discharge experience more delightful” (p. 42). The leadership program initiated with design thinking training after which point participants worked in groups of four and checked in with a design thinking coach once per week. Weekly emails asked participants to respond to prompts that included creative agency and creative growth mindset surveys that had been used in previous studies. Additionally, the prompts were designed to capture “snapshots” of activity. These snapshots were comprised of several numeric questions accompanied by short answer responses. An example of the prompts and questions is reproduced in Table 12.

Table 12

Example of Snapshot Prompts

Prompt	Numeric question	Short answer question
Empathy	Number of users spoken to?	What did you learn?
Prototype	Number of prototypes created or iterated on?	What are you testing?
Test	Number of people tested prototypes with?	What did you learn?
Collaboration	How in sync is your team?	How could it change?

Note: From "Mapping and measuring applications of design thinking in organizations." by A. Royalty and B. Roth, 2016, Design Thinking Research, p. 42. Copyright 2016 by Springer Nature. Reprinted with permission.

Using a 1-6 scale, the design thinking coaches rated employees every three months in the design thinking areas of empathy, define, ideate, and prototype. The example of the design thinking coach evaluation form is reproduced in Table 12 below.

Table 13

Expert Coach Evaluation Measures

Category	Question 1	Question 2	Question 3
Point of view	How in sync are individuals around their POV?	How meaningful is their POV?	NA
Ideation	How novel are the ideas?	How meaningful are the ideas?	How wild is the wildest idea?
Prototyp e	How novel are the prototypes?	How meaningful are the prototypes?	How useful are the prototypes?

Note: From "Mapping and measuring applications of design thinking in organizations." by A. Royalty and B. Roth, 2016, Design Thinking Research, p. 42. Copyright 2016 by Springer Nature. Reprinted with permission.

Both pilot studies were intended to develop measures that could be used on a large scale to statistically describe and predict design thinking in the workplace.

In this pilot study, data from the employee prompts (55% response rate) and design thinking coach employee evaluations were used to generate creative output scores which were used to rank teams according to their empathy and creative output scores. The researchers imagined there could be a correlation between empathy and creativity scores but realized the sample size was too small to support that conclusion. The researchers reported that this data was already being used by the design thinking coaches to track employee activity and speculated employees might use the data in sharing activities.

The researchers also said that a current need for design thinking is ways to assess its impact. Writing from the field of nuclear engineering, (Menold et al., 2017) justified the use of human-centered design methods by noting that user satisfaction positively correlates with increased revenue. " Specifically, Anderson et al. (1994) found that a one-point increase in user satisfaction could result in an 11.4% increase in return on investment" (p. 91).

This effort might be more effective if less obtrusive measures were used (Russell & Kovacs, 2006; Shute & Kim, 2014). Also, it is questionable if the instruments are sensitive enough to reach conclusions about creativity or empathy. Finally, motivation might be improved if results were used as part of a mastery orientation in lieu of the performance orientation (Ames, 1992) described, and data was used for formative feedback as opposed to external evaluation (Havnes, Smith, Dysthe, & Ludvigsen, 2012; Shute, 2008).

Royalty and Roth (2016) continued to work to test and develop assessment instruments for the measurement of constructs related to design thinking. Two studies were reported. In the first study, a pre-post survey was administered to both prospective and active students in the d.school. In the second study, a series of measures was developed and administered within professional contexts that involved four businesses that were implementing design thinking training and practices within their company cultures.

The first study used an assessment instrument derived from a previously developed survey instrument called the *competency-based creative agency scale* (Royalty et al., 2014). This section of the survey consisted of 11 five-point Likert scale items. The next part of the survey was a creative growth mindset scale consisting of 3 six-point Likert scale items. The remaining part of the survey consisted of demographic questions. The pre-survey was administered online to prospective students of a "Bootcamp" course, and the post-survey was administered once students completed the course. Over 120 applicants completed the initial survey, and due to attrition, a total of 31 pre-post surveys were collected from students in the Bootcamp course.

A paper-based version of the same survey was administered to students in a product design course that included "topics related to innovation but does so using a more traditional educational model" (p. 174). Of the possible 45 students, 31 completed both the pre and post surveys.

Although data analysis was not yet complete at the time of the report, the data that was available indicated a positive change in creative agency for those students who completed the Bootcamp and no change in creative agency for students in the product design course. Data indicated a slight positive change in a growth mindset for those students who completed the Bootcamp and no change in a growth mindset for students in the product design course.

For the second study, researchers conducted eight semi-structured interviews with design thinking coaches that trained employees in design thinking methods within the companies. Coaches were provided with handouts that consisted of templates for blank timelines to be filled out by the design thinking coaches. These timelines were intended to represent the design thinking coaches' experience in conducting design thinking training with other employees and to indicate movement through the training process. The collected data was next analyzed in tandem with the design thinking coaches to develop categories and further refine the instrument with an eventual goal of quantizing the qualitative data into normative categories of high, medium, or low.

The results included three main categories that represented why the firms initially engaged with design thinking. The categorical reasons for adopting design thinking were (a) a perceived companywide disconnect from end users, (b) fear of startups taking new business opportunities, and (c) desires for teams to work in more innovative ways. Using this data, four new categories were formulated that were in turn used to assess four constructs. The four constructs were (a) empathy, (b) reframing, (c) iteration, and (d) team collaboration.

The empathy assessment instrument was intended to gauge how connected teams were to the end users and collected data in response to the following three queries: (a) the number of days that had passed without making contact with the customer, (b) the number of stakeholders spoken with regarding review of prototypes, and (c) the different types of customers spoken with, where the type was defined by the company. These measures were intended to assess empathy according to how frequently employees interacted with customers and how varied the customers' types were.

The reframing assessment instrument was a graphic survey that employees filled out anonymously. Employees were asked to rate a project objective along the two dimensions of value and novelty. An x-y grid was used. Novelty was indicated by marking along the x-axis continuum that ranged from “not novel” to “novel.” Value was indicated by marking along the y-axis continuum that ranged from “not valuable” to “valuable.” In this way, the value and novelty scores for a given project objective could be aggregated and weighted for each individual employee.

The iteration assessment instrument involved two measures. The first measure was the number of prototype iterations performed by individuals or small groups. The data was captured by asking team members to “list each iteration they create and what they hope to learn from it” (p. 180). The second measure was the number of prototypes being worked on in parallel. Active or closed prototypes were indicated by team members marking either “open” or “closed” on the prototypes with which they worked. The team collaboration assessment instrument was referred to as the “Interaction Dynamics Notation tool created by Neeraj Sonalkar and Ade Mabogunje”

(p. 181). Researchers indicated this tool involved video of team interactions that would be submitted for analysis. No further information was provided.

Working from the field of engineering, Blizzard et al. (2015) have also developed a survey instrument to assess design thinking traits. The survey consisted of nine statement items that were mapped onto a five factor structure that represented design thinking traits and was scored along a five-point Likert response scale. Table 14 shows the traits mapped onto the five factors and the corresponding statement items.

Table 14

Design Thinking Factors, Traits, and Survey Items

Design thinking factors and traits	Statement items
Feedback Seekers They ask questions and look for input from others to make decisions and change directions.	• I seek input from those with a different perspective from me. • I seek feedback and suggestions for personal improvement.
Integrative Thinking They can analyze at a detailed and holistic level to develop novel solutions.	• I analyze projects broadly to find a solution that will have the greatest impact. • I identify relationships between topics from different courses.
Optimism They don't back down from challenging problems.	• I can personally contribute to a sustainable future. • Nothing I can do will make things better in other places on the planet (negative).
Experimentalism They ask questions and take new approaches to problem solving.	• When problem solving, I focus on the relationships between issues.
Collaboration They work with many different disciplines and often have experience in more than just one field.	• I hope to gain general knowledge across multiple fields. • I often learn from my classmates.

Note: From "Using Survey Questions to Identify and Learn More About Those Who Exhibit Design Thinking Traits." by J. Blizzard, L. Klotz, G. Potvin, Z. Hazari, J. Cribbs, and A. Godwin, 2015, Design Studies, 38, p. 103. Copyright 2015 by Elsevier. Reprinted with permission.

To develop the design thinking statements, researchers reviewed the design thinking literature as summarized in (Blizzard, Klotz, Pradhan, & Dukes, 2012; Blizzard & Klotz, 2012) and generated the 18 statements displayed in Table 15.

Table 15

18 Potential Design Thinking Questions

All 18 potential design thinking questions
Helping others (respondents indicated the importance of statement)
I seek input from those with a different perspective from me
I think of myself as part of nature, not separate from it
I prefer to focus on details and leave the big picture to others
I prefer to focus on the big picture and leave the details to others
I identify relationships between topics from different courses
I analyze projects broadly to find a solution that will have the greatest impact
When problems solving, I focus on the relationship between issues
When problem solving, I optimize each part of a project to produce the best result
Solving societal problems (respondents indicated importance of statement)
Environmental problems make the future look hopeless
I can personally contribute to a sustainable future
Nothing I can do will make things better in other places on the planet
Inventing/designing things (respondents indicated importance of statement)
I seek feedback and suggestions for personal improvement
Working with people (respondents indicated importance of statement)
I hope to gain general knowledge across multiple fields
I often learn from my classmates

Note: From "Using Survey Questions to Identify and Learn More About Those Who Exhibit Design Thinking Traits." by J. Blizzard, L. Klotz, G. Potvin, Z. Hazari, J. Cribbs, and A. Godwin, 2015, Design Studies, 38, p. 100. Copyright 2015 by Elsevier. Reprinted with permission.

The initial drafts of the statements were refined based on feedback from "…educators with expertise in design thinking" (Blizzard et al., 2015, p. 95). The statements were aggregated, administered as a survey, and piloted across several iterations with two groups of students from two different 4-year institutions. Also, student focus groups were used to gather data surrounding the interpretation of the survey questions. The result from this set of procedures was either a redrafting or elimination of the individual statements to improve the clarity, face validity, and content validity. The outcome of this process was a set of 18 statements "..intended to identify design thinkers" (Blizzard et al., 2015, p. 94).

The next step was to append these 18 statements to a pre-existing instrument, The Sustainability and Gender in Engineering (SaGE) survey. This hybrid of the design thinking traits statements and the pre-existing SaGE survey were then administered to a random sample of 50 higher education institutions across the United States. Responses (N=6772) were received from all 50 institutions surveyed. Exploratory factor analysis was applied to the survey response data and resulted in the reduction of the 18 initial design thinking statements to a total of nine design thinking traits statements.

Blizzard et al., (2015) used exploratory factor analysis to identify which statement items positively or negatively correlated with other statement items in the set. The highly correlated statement items were assumed to likely be influenced by the same underlying factors and were therefore reduced and collapsed. Statement items that had a low correlation with the other statement items in the set were assumed to likely have different underlying factors and were therefore retained. Through this process of exploratory factor analysis, the total number of survey items was reduced to the nine design thinking traits statements used in this study.

Blizzard et al., (2015) also used statistical analysis to identify themes relating to the initial 18 item statements which resulted in the identification of five underlying factors, which were used to categorize the nine-item statements resulting from exploratory factor analysis. These five factors, shown in Table 14 with trait definitions and in relation to the nine survey statements, are:

1. Feedback seekers
2. Integrative thinking
3. Optimism
4. Experimentalism
5. Collaboration

The researchers used five different approaches (four statistical and one literature-based) to guide interpretation of the data and map this five-factor structure to the nine design thinking statements. When applied to the original 18 design thinking statements, a scree-test recommended the extraction of nine factors while parallel analysis recommended the extraction of eight factors. Blizzard et al., (2015) then created a matrix showing the correlations between each pair of questions and conducted a cluster analysis resulting in a recommendation to reduce the number of factors to less than either the scree-test or parallel analysis suggested.

To measure the internal consistency of the statements and determine if they measured the same latent construct associated with design thinking, Blizzard et al., (2015) calculated a Cronbach's alpha value. A single latent construct "...is a variable that cannot be directly observed, but is instead inferred from other variables that can be" (Blizzard et al., 2015, p. 104). Calculations yielded a Cronbach's variable of 0.76—just over the 0.7 value generally considered to indicate a set of statements measures a single latent construct (Peterson, 1994). Design thinking literature helped inform the decision to settle upon five underlying factors that aligned with the design thinking statements since "…design thinking is typically defined with fewer characteristics than the scree and parallel analysis tests were recommending" (Blizzard et al., 2015, p. 99).

The nine statements might be helpful for defining design thinking behaviors, but the authors cautioned against working toward a singular definition of design thinking. They noted the variety of design thinking definitions in the literature and said, "This ambiguity should be embraced; a constant definition is not necessarily needed, or even desirable" (Blizzard et al., 2015, p. 93).

Kienitz et al. (2014) conducted a randomized controlled pilot study (N=28) testing two separate interventions for their effects on creative capacity and relationship to personality traits. The intervention was a five-week creative capacity building program, and its control was a five-week language intervention. The intervention was "...an abbreviated version of a highly popular class offered at the Stanford Design Institute called 'Creative Gym'" (p. 60). The pedagogy of the *Creative Gym* aligns with perspectives from the design thinking literature, as can be seen in the authors' broad description of course activities: observe, brainstorm, synthesize, prototype, and implement." (p. 60).

The control group underwent a five-week language learning program that did not encourage or facilitate creativity. Researchers used the *Torrance Test of Creative Thinking* Figural Assessment (TTCT-F) as a pre and post measure of creative capacity. The TTCT-F measures characteristics of divergent thinking represented by the subscales: *fluency*, *originality*, *abstractness of titles*, *elaboration*, and *resistance to premature closure*. No significant difference was found when comparing average TTCT-F scores between the experimental and control groups. Significant differences were found between groups when comparing the subscales of *elaboration* and *resistance to premature closure*.

The researchers suggest the *Creative Gym* intervention may be responsible for increased scores on the subscales of elaboration and resistance to closure, but that more research is required, along with larger sample sizes. This study had a total of 28 participants, with fifteen of them in the experimental group and thirteen of them in the control group. This research suggests that interventions involving a design thinking influenced pedagogy may result in an increased capacity for some kinds of divergent thinking abilities, and perhaps that experimental, randomized controlled studies may not be the best fit for research into small groups.

The study compared participants scores on TTCT-F with scores on the NEO Five-Factor Inventory (NEO-FFI). Results showed a positive correlation between *resistance to premature closure* and the personality trait *Extraversion*.

Ejsing-Duun and Skovbjerg (2018) conducted research as part of a program titled "Design Thinking and University Pedagogy" at Aalborg University, Copenhagen. Design as a method of inquiry (Dewey, 1938b) was applied through three different pedagogical modes for an undergraduate course where student projects focused on helping the National Gallery of Denmark reach its goal of "making the fixed exhibitions more attractive to visitors and more interesting for employees" (p. 2).

The three different modes of design inquiry were (a) design as practice, (b) design as research, and (c) design as critical theory and inspired by the work of Schön (1983), Squire and Barab (2004), and DiSalvo (2009, 2012), respectively. As a result of using design as a strategy for inquiry "students are provided with more opportunities for action as design approaches include exploring the subject through visualization and materialization, and the methods for knowledge production are expanded" (p. 1).

The research goal was to explore students' design and learning experience. A mixed method approach was used that involved data collection via observations, participatory observations, student designs, questionnaires, and interviews. Participants included 225 students and four teachers. All students used the three different modes of design-based inquiry to work on the design goal which was supplied by the museum's need.

In the design as practice mode, students created products and engaged with problem finding, problem framing, reflection on action, divergent thinking, and convergent thinking. In the design as research mode, students engaged in topic research, participatory observation, prototyping, testing, iterating, design logging, and reporting. In the design as critical theory mode, students engaged with the "political aspects of a museum selecting, archiving and displaying chosen works for the public" (p. 13). This mode of design-based inquiry would "challenge the assumption that educated art curators should choose what is displayed at a museum" (p. 13) and resulted in students' proposed voting systems that allowed the museum-goes to have a voice in what art was displayed on the museum floor.

The researchers suggested multiple modes of design-based inquiry to "nuance the concept of inquiry and thereby strengthen the concept's pragmatic contribution to design pedagogy and design thinking" (p. 14). A fourth "meta-mode" of inquiry was proposed to scaffold student reflection throughout course work. The researchers advised educators to become aware of these multiple modes of inquiry so to replace single with multiple modes to manage the complexity of the process. This would provide access and ways of talking about design that could legitimize "the design process as a means of abductive thinking in academic settings dominated by inductive and deductive reasoning" (p. 14).

Dorst (2015) used the concept of abduction to develop the concept of "frame creation" as an alternative to conventional approaches to problem-solving and as a suggested expansion for the field of design. For Dorst, the central challenge of design is design abduction. Dorst's summary of design abduction is as follows:

> In design abduction, the starting point is that we only know about the nature of the outcome and the desired value we want to achieve. So, the challenge is to figure out "what" to create, while there is no known or chosen "how," that we can trust to lead to the desired outcome. Thus, we have to create or choose both a "what," and a "how"—as these are quite dependent on one another, they should be developed in parallel. This double creative leap requires designers to devise proposals for both the "what" and the "how," and test them in conjunction. (Dorst, 2015, p. 25)

The process of figuring out "what" to create involved a hypothetical way of looking at the problem, which Dorst called "framing" and "the key to design abduction" (p. 25). Dorst proposed a nine-step model for a process he termed “frame creation.” The process steps are reproduced in Table 16.

Table 16

Nine-step Frame Creation Model

Step	Description
Archeology	Analyzing the history of the problem owner & the initial problem formulation
Paradox	Analyzing the problem situation: what makes this hard?
Context	Analyzing the inner circle of stakeholders
Field	Exploring the broader field
Themes	Investigating the themes that emerge in the broader field
Frames	Identifying patterns between themes to create frames
Futures	Exploring the possible outcomes and value propositions for the various stakeholders
Transformation	Investigating changes in stakeholders’ strategies and practices required for implementation
Integration	Drawing lessons from the new approach & identify new opportunities within the network

Note: From "Frame Creation and Design in the Expanded Field." by K. Dorst, 2015, She Ji: The Journal of Design, Economics, and Innovation, 1, pp. 26-27. Copyright 2015 by Tongji University and Tongji University Press. Reprinted with Creative Commons Attribution 4.0 International license.

The first four steps laid the groundwork for an approach to the problem. The middle step, Themes, was central to the process and guided the last four steps of the process that involved possible applications of the identified themes. This was an example of adopting a single aspect of the design process, framing, as a stand-alone alternative to traditional problem-solving processes. Dorst and colleagues have conducted “over 140 experimental Frame Creation projects” in partnership with local civic research centers and international academic partners “The Hague University, Hong Kong Polytechnic, University of the Arts London” (p. 27).

Dorst then discussed some challenges to the field of design. The frame creation process, for example, requires a deep understanding of the design context, the involvement of multiple stakeholders, and the need to leave the problem-solution space open so that the right approach can materialize. This requires designers to leave the “white space” of their offices and become embedded in the field. During the past 20 years, the design process has become decentralized which in turn challenged the rigor and coherence with a scattering of design inputs and expertise.

As an example of the decentralization of design practice, a university undergraduate degree program called the “Bachelor of Creative Intelligence and Innovation” (p. 32) involves learning within 24 different degree programs across the university which is characterized by “networked problem solving and complex transdisciplinary collaboration” (p. 32). Dorst suggested this arrangement may predict upcoming changes to the way design and design education is practiced in the future.

Project-based learning and design thinking. Since design thinking almost always revolves around projects, project-based learning and design thinking are an excellent fit. For this study, design thinking occurs within a project-based learning environment. Although project-based learning is widely practiced, definitions or guidelines for it vary and have changed over time. Thomas's (2000) review of the literature found commonalities across different instances of project-based learning and identified five criteria learning environments should meet to be project-based learning: *centrality, driving questions*, *constructive investigations*, *autonomy*, and *realism* summarized in Table 17. According to Thomas, project-based learning involves student choice around authentic projects. Project-based learning instruction should allow for driving questions that expose students to selected disciplines or subject matter.

Table 17

Project-based Learning Criteria as Identified by Thomas (2000)

Criterion	Description
Centrality	PBL projects are central, not peripheral to the curriculum. Corollary 1: First, according to this defined feature, projects are the curriculum. Corollary 2: Second, the centrality criterion means that projects in which students learn things that are outside the curriculum ("enrichment" projects) are also not examples of PBL, no matter how appealing or engaging.
Driving question	PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline.
Constructive investigations	Projects involve students in a constructive investigation.
Autonomy	Projects are student-driven to some significant degree.
Realism	Projects are realistic, not school-like.

Note: Adapted from "A Review of Research on Project-Based Learning." by J. W. Thomas, 2000, Retrieved from http://www.bie.org/object/document/a_review_of_research_on_project_based_learning

Building from Thomas's (2000) paper, Condliffe's (2017) review of the literature included a list of seven papers offering 43 design principles for project-based learning environments and added additional guidelines for project-based learning environments as displayed in Table 18.

Table 18

Project-based Learning Criteria as Identified by Condliffe (2017)

Criteria	Question - Description
Curriculum Design Principles	*What Is Taught in a PBL Approach*? Driving Questions to Motivate Learning Target Significant Learning Goals Use Projects to Promote Learning Dedicate Sufficient Time to PBL
PBL Instructional Approaches	*How Do Students Develop New Skills and Knowledge in a PBL Classroom?* Promote Construction of Knowledge Cultivate Student Engagement Use Scaffolds to Guide Student Learning Encourage Student Choice Support Collaborative Learning
Assessment Design Principles	*How Do Students Demonstrate Learning in a PBL Setting?* Create a Product That Answers the Driving Question Provide Opportunities for Student Reflection and Teacher Feedback Present Products to Authentic Public Audiences

Note: Adapted from "Project-based Learning: A Literature Review." by B. Condliffe, 2017, Retrieved from MDRC website: https://s3-us-west-1.amazonaws.com/ler/MDRC+PBL+Literature+Review.pdf

These lists describe project-based learning environments and the projects. There is less focus on how project work is carried out and the creative strategies students might use to innovate with project work. Project-based learning involves student choice and project work as a way of learning. The choice aspect of project-based learning gives students a large amount of autonomy in their work. This large degree of freedom may sustain motivation levels for some students but be intimidating for others. Design thinking can offer practical guidance for conducting project work. Beyond practical guidance, design thinking offers strategies for creating value in the face of problems and uncertainty. Another set of guidelines for PBL have been described as “gold standard” (Larmer et al., 2015) project-based learning includes the following seven qualities of project-based learning. Projects should have the following characteristics: (a) challenging problem or question, (b) sustained inquiry, (c) authenticity, (d) student voice and choice, (e) reflection, (f) critique and revision, and (g) public product. Although there is no strict definition for project-based learning, the guidelines discussed here suggest the minimum qualifications for project-based learning according to that described by Condliffe (2017) and Thomas (2000).

It seems reasonable to assume that instructional designs grounded in project-based learning have significant parallels with the design thinking method, even when design thinking is not explicitly considered during the design of the course. Dym et al. (2005) describe the integration of project-based learning and design thinking in courses designed for engineering students. In higher education, and especially in the domains of engineering and art, there is some evidence of project-based instructional approaches complemented by ideas from design thinking. Project-based learning and design thinking seem to have a symbiotic relationship that is becoming apparent to instructors and researchers in higher education. Petrucco and Ferranti (2017) used an innovative combination of project-based learning and design that was informed by activity theory. Activity theory is a generic analytical research framework that, like design thinking, is also a systems method. Like design thinking, activity theory can be used to suggest creative development cycles that are informed by user needs and the surrounding context. The authors note how their students viewed the activity framework as helpful to their project work, which was to design an app to support “Smart Cities” interventions in Europe intended to increase the effectiveness of city planning. The resulting app was published and used by thousands of citizens and deemed a success in its ability gather the multiple perspectives stakeholders and resolve some of the contradictions between them. The larger point here is that design thinking is also a systems approach to design and it should be seen as a natural fit and helpful scaffold for project-based learning.

Research suggests that project-based learning environments have positive effects on student motivation (Blumenfeld et al., 1991; Condliffe, 2017; Stefanou, Stolk, Prince, Chen, & Lord, 2013). Moreover, the positive correlation between learner autonomy and motivation might also correlate with playful attitudes and approaches to project work that support flow experience. When Primus and Sonnenburg (2018) investigated the flow experience (Csikszentmihalyi, 2014) of 29 German graduate students engaged with design thinking exercises, they set experimental conditions that mimicked the autonomy and open-ended nature inherent to project-based learning. Interested in the relationship between design thinking tasks on group and individual flow experience, the authors asked participants to complete two tasks during a one-day workshop. Their experimental design also measured the effect of a skills building creative warm-up exercise, the Lego Serious Play (LSP) process, to find if it would have a "positive effect on creative flow" (Primus & Sonnenburg, 2018, p. 105). The researchers noted criticism that suggested design thinking interventions "may be too rational and focused on efficiency to evoke creative flow" (p. 105) and suggested that design thinking interventions might be made more effective if they included more support for creativity and flow. This leads to the idea that project-based learning can provide a framework to support the development of design thinking, and that design thinking can offer a systems approach to design that supports the navigation of project work.

Participants were split into two groups and formed three teams per group. Each group worked on the first task in the morning and the second task in the afternoon. Environmental conditions for the tasks were (a) open-ended, (b) involved giving students control over the tasks, and (c) minimized fear of failure—these conditions coincided with the high learner autonomy and open-endedness associated with project-based learning. The morning task involved finding solutions to support healthy student lifestyles and the afternoon task involved finding solutions that helped students, alumni, and professors interact in creative ways. Each group participated in the Lego Serious Play creative warm-up activity, but one participated before the morning task and the other group participated before the afternoon task. Both groups engaged with exercises that supported the design thinking process delineated by the steps of empathize, point of view, ideate, and prototype (D.School, 2019).

The authors called for more research into the relationship between the kinds of tasks/problems and flow experience in co-creative settings and suggested facilitators of these kinds of workshops include additional supports for creativity, such as the Lego Serious Play creative warm-up used in the study. Both individuals and groups reported higher levels of flow in the morning tasks that involved healthy lifestyles and reported lower levels of flow for the afternoon tasks that involved connecting students, alumni, and professors in creative ways. It was suggested this might have been due to the varying appeal of the topics and the length of the creative warm-up activities. Finally, group flow in design thinking activities was associated with individual flow, and the researchers noted this was the first study of its kind to contextualize design thinking and flow experience. Apparently, interventions that support creativity can increase the flow experience for students who engage with design thinking activities framed as workshops. Interesting questions arise from these findings concerning project-based learning and how it might affect design thinking over the duration of longer projects.

These researchers selected a play-oriented activity for the creative warm-up exercises. This suggests an interesting link between play, project-based learning, creativity, and design thinking. Interventions that are designed with goals to excite a sense of play via project work could result in increased student engagement and learning. Play should not be considered as separate from learning and could easily be a part of project work. After all, the high levels of motivation associated with project work implies that the work is enjoyable. Beliefs that play is somehow antithetical to learning are misguided and, “These misconceptions are all unfortunate because the extensive research on play with children and adults in anthropology, psychology, and education indicates that play is an important mediator for learning and socialization throughout life (Blanchard & Cheska, 1985; Csikszentmihalyi, 1990; Provost, 1990; Yawkey & Pellegrini, 1984)” (Rieber, 1996, p. 44). Moreover, play is an alternative to traditional modes of learning that emphasize reading and writing. For example, play can be visual. In this light play is a visual and kinesthetic way of making thinking visible that aligns well with design and design thinking. Vygotsky (1978) has noted the connection between play, visual thinking, and subsequent learning.

> It is the essence of play that a new relation is created between the field of meaning and the visual field—that is, between situations in thought and real situations. Superficially, play bears little resemblance to the complex, mediated form of thought and volition it leads to. Only a profound internal analysis makes it possible to determine its course of change and its role in development. (Vygotsky, 1978, p. 104)

Project-based learning has the potential to frame the elements of flow experience, play, creativity, and design in ways that can help instructors and students use project work to practice creative and social skills while learning new methodologies for accomplishing work, such as design thinking.

Design thinking and education. Ilhan (2017) tracked the growth of design education for undergraduates from 1988 through 2012 and found it to be outpacing both engineering and the visual arts. However, design education was found to be moving *away* from doctoral/research universities. The largest gains and fastest rates of growth were within private universities and colleges. The steady decline of design education in doctoral/research university implies a questionable future for research into design since baccalaureate colleges, master's colleges, and universities general focus on teaching and not on research. The author speculated the decline of design education within the research universities reflected trends in the federal allocation of grants for research. This speculation was based on analysis of design funding according to four Carnegie types of classification that showed the only area in decline to be doctoral/research universities.

Interestingly, Dym et al. (2005), writing from the field of engineering, called for an increase in resource allocation for design coaches with expertise in creativity to improve outcomes for engineering students. Three of the four authors were from doctoral/research universities and all but one of the four were from private not-for-profit universities. Hopefully it was not the fact that most authors wrote from positions in non-publicly funded universities that allowed them to invest their research time and resources into creativity, design, and project-based learning in higher education. If that were the case it would be unfortunate, because all institutions of higher education could increase the value they offer students by investing in these kinds of interventions. Engineering has been a leading domain in innovating project-based learning in higher education, and it seems reasonable that design methods from different domains could be productively blended and applied in other domains, especially since there is a growing body of research that suggest some common design abilities and dispositions in play across various applications of design (Cross, 2015).

Norman and Klemmer (2014) argued for a change in design education and suggested the institutional norms cemented into university structures elevate the specialist over the generalist. This situation was a barrier to design educators acting as generalists "who can cut horizontally across many of the deep, vertical specialties" (p. 1). For Norman, design education needs a new vision of curriculum where generalists and specialists collaborate across disciplines, enabling design to once again serve the needs of the times by aligning educative experiences with 21st-century challenges and developing a design theory fitted with the context of higher design education.

Rauth et al., (2010) framed design thinking as "a metadisciplinary concept and education model" (p. 1) with the assumption that "design thinking creates mindsets that in sum build creative confidence" (p. 1). Principles of design thinking were summarized with the seven basic tenets of design thinking. These tenets were (a) human-centered, (b) mindful of process, (c) empathy, (d) culture of prototyping, (e) show don't tell, (f) bias toward action, and (g) radical collaboration. The authors interviewed 17 teachers from the d.school campuses in Stanford and Potsdam to learn their views on design thinking and on teaching design creativity.

The teachers said that students were exposed to basic methods and tools early in the course, with more specialized tools added as the course unfolded. The exact type of tools depended on the students and the instructors' abilities, but all students were exposed to brainstorming, drawing, and prototyping early in the process. Students' progressed through five different modes, with each mode corresponding to a design thinking methodology and conceptual or physical tool. The modes were (a) empathize, (b) define, (c) ideation, (d) prototyping, and (e) test. The process was demonstrated to students before they were expected to perform independently. Also, they were given predefined creative challenges. This scaffolding was faded, and the supplied challenges became increasingly vague. When asked about mindset development, the teachers could not provide full descriptions, and the researchers assumed this lack of description suggested that mindset was a relatively new and undeveloped pedagogical construct for the teachers.

Most of the teachers emphasized creative confidence as an important student outcome and defined it as a "development of trust in one's own creative skills" (p. 6). The teachers saw the methods and tools used as methods of creative expression oriented toward creativity and creative problem-solving. The researchers concluded with a model for the development of creative confidence that involved the building blocks of (a) methods, (b) design thinking process, (c) mindsets, and leading to (d) creative confidence. These teachers began with demonstrations of the process, a basic toolset, and supplied challenges. This scaffolding was gradually faded, and students were given increasingly vague problems to address. Not all researchers were clear about mindsets, but they were unified in the agreement that creative confidence was the primary outcome for students.

The potential value for design as education has been broadly expressed across time and disciplines (Archer, 1979; Buchanan, 1992; Cross, 2018b; Dewey, 1913, 1938; Infosys Foundation USA, 2017; Papert & Harel, 1991; Simon, 1969). The benefits of learning to generate, express, and implement creative ideas will manifest once students enter their professions and grapple with ill-structured and often undefined problems. Nelson and Stolterman (2003) suggested “Humans did not discover fire—they designed it” (p. 71). Why not seriously consider the design of our future? Nigel Cross, an established scholar of design, shared visions for design research that had a compelling mixture of boldness and humility:

> I think the discipline of design could benefit from a much more progressive and coordinated research programme, rather than the fragmentation that seems evident today. It needs a solid, collective viewpoint instead of idiosyncratic, personal views of what constitutes design research; it needs significant leadership and an honest acknowledgement from people within the field that we are all still novices in design research. (Cross, 2018, p. 707)

Design resists being pinned down. It has been used throughout history by a multitude of individuals and domains. It is such a fundamental human ability that it goes with us wherever we go. The ways of design have been shaped by history, society, culture, and technology. Efforts to build a unified theory of design are resisted by its contextual dependence and nomadic quality. Design wanders from one historical scene to the next, across one thousand plateaus, setting temporary roots in various domains according to need. Design is applied creativity. As the fields of anthropology and archaeology intuitively understand, design reflects the needs, values, and aspirations of the time.

Related to the idea of design as a fundamental human ability is the problem of specialized labels for design theory. The term “design thinking” indicates a human-centered collection of methods and attitudes for addressing complex and ill-structured problems. In contrast to the hard systems methods, design thinking is lightweight and does not require advanced degrees to understand and implement. The term “design thinking” does have a rich history, especially with its connection to design as education. But is still only a label, as David Kelley clarified in a recent interview, "All those years I said 'You’re experts at design methodology,' nobody paid attention.

They didn’t take it as a new idea or a novel idea. They didn’t believe it. For some reason, the words 'design thinking' resonated with them" (Camacho, 2016, p. 89). Ultimately, how design is carried out and what it accomplishes is of more interest than the labeling of it.

Activity Theory

This section of the literature review will focus on activity theory and its origins, foundational concepts, modern variations, and application within learning contexts. The review will describe the historical context and ideas of Hegel, Marx, Vygotsky, and Leont’ev that comprise the foundational concepts of activity theory. Next, the modern version of activity theory will be described, with preference placed on the contributions of Engeström. This section concludes with examples of activity theory applied to a variety of learning contexts with emphasis placed on its use in formative intervention research.

Activity theory evolved from the work of Russian teacher and psychologist L. S. Vygotsky, who pioneered research into developmental learning that rejected behaviorism’s epistemology and stimulus-response model as a way of understanding human learning, which was the scientific convention of his time. Activity theory is an analytical framework that evolved from Vygotsky’s research methods and is based on his original concept of *the zone of proximal development* (Vygotsky, 1978, p. 86) and *the functional method of double stimulation* (p. 73). It is intended to capture the socio-cultural context of learning and its historical development. Within and between activity systems, tensions and contradictions are used as markers of potential development. Contradictions are instantiated by a complex of factors and depend upon learners’ interactions with systems and their components. The idea of contradiction, or antithesis, descended from the Hegelian dialectic that was adapted by Engels and Marx to explain change in terms of human practical activity in the world. These ideas shaped Vygotsky’s research methods which centered on mediated human activity within historical and socio-cultural contexts. His methods were framed by his concept of the zone of proximal development which serves as the core analytic feature of activity theory:

> We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement. (Vygotsky, 1978, p. 90)

Vygotsky and his colleagues worked from a common epistemology to create a framework for the analysis of human activity.

Origins. In 1917, building historical tensions erupted across Russia with the Bolshevik Revolution, civil war, famine, and Stalin's eventual rise to power. An urgency to transform the abilities of Russia's working class from agricultural into industrial skills spurred calls for increased education. Illiteracy was widespread, and two years after Vygotsky graduated from Moscow University in 1917, Lenin laid plans to eradicate illiteracy by a 1919 decree. Classes were held in factories, barracks, and teachers followed nomadic tribes as part of the plan to modernize Russia. Meanwhile, opposing factions of Russian Marxists intensely debated the meaning of materialism, which only served to further entrench the positions of each faction. The left-wing, known as the "dialecticians," held that consciousness and free will accounted for change whereas the right-wing, known as the "mechanicists," held to beliefs of determinism and that genetics were responsible for change, a stance that had the effect of limiting the political will of the people (Rosa & Montero, 1990). It was against this background that Vygotsky secured a job in Moscow where he worked at the Institute of Psychology and assembled a small group of young scholars who would go on to create a school of Soviet psychology.

Amongst the upheavals of economic crisis and ideological in-fighting, the Communist Party, which increasingly exerted ideological control over scientific research, found itself in need of a new psychology of human behavior. State control over psychologists and their research peaked in 1936 with the decree “On the Pedological Perversions in the System of the People’s Commissariat for Education” (Rosa & Montero, 1990, pp. 70–71) and by this time Vygotsky, unable to find an independent research position in Moscow, accepted an offer from Kharkov in the Ukraine, where his colleagues set up shop while he remained in Moscow and visited as possible.

Vygotsky died in Moscow in 1934. He was 38 years old. The Stalinist Party repressed his work and that of his group for years thereafter and forbade his works to be discussed or disseminated until after Stalin’s death in the mid-1950s (Davydov, 1995). His works only began trickling out to the West in the 1960s. After Vygotsky, the remaining group of scholars, most notably A.N. Leont’ev (1904-1979) and A. R. Luria (1902-1977), continued with research, expanded upon Vygotsky’s work, and formulated activity theory.

Vygotsky, Dewey, Mead. Although isolated by continents and political turmoil, Vygotsky’s activity-oriented ideas of learning ran in parallel with American pragmatism, and especially with John Dewey’s (1859-1952) view of practical activity, “…the chief task of knowledge turns out to be to demonstrate the absolutely assured and permanent reality of the values with which practical activity is concerned" (Dewey, 1929, p. 35). Another parallel was found between Vygotsky’s view of social learning and Georgie Herbert Mead’s (1863-1931) view of the social nature of thought, “…since reflective thought is a social undertaking and since the individual in whose experience both the problem and its solution must arise presupposes the community out of which he springs” (p. 60).

Vygotsky and contemporary scholars. Contemporary scholars (Engeström & Miettinen, 1999; Jonassen, 2002) connected activity theory’s epistemological orientations with other learning theories and constructs which include situated learning and legitimate peripheral participation (Lave & Wenger, 1991), distributed cognitions (Salomon, 1993), co-construction, co-evolution (Durham, 1991), and interactive system models. Other obvious connections are with active pedagogies such as project-based learning, constructionism (Papert & Harel, 1991) and various iterations of the maker movement (Martinez & Stager, 2013). Activity theory has even been theorized in terms of constructivist course designs (Jonassen & Rohrer-Murphy, 1999). Overall, activity theory connects with any epistemology or pedagogy assigning a value to learning by doing and active approaches to learning in general.

Unfortunately, negative opinions about Marxism, the philosophical foundation of activity theory, may be responsible for some limitations on its use. To be sure, Vygotsky and his colleagues viewed Marxism and the mechanic of dialectical materialism as the blueprint for rebuilding the theoretical framework of psychology. And yet, Vygotsky was a psychologist interested in understanding human learning and development first and foremost:

> I don't want to discover the nature of mind by patching together a lot of quotations. I want to find out how science has to be built, to approach the study of mind having learned the whole of Marx's *method*….The whole of *Capital* is written according to the following method: Marx analyzes a single living "cell" of a capitalist society—for example, the nature of value….Anyone who could discover what a "psychological" cell is—the mechanism producing even a single response—would thereby find the key to psychology as a whole. (Cole & Scribner, 1978, p. 8)

Activity theory and Marxism. When Vygotsky's colleague A. N. Leont'ev sketched the morphological categories of an activity system and the hierarchical categories of activity as the primary unit of analysis for human development, and it was precisely this effort to operationalize a "psychological" cell. Dialectical materialism within a historical and social-cultural context was used to explain developmental change. These ideas are taken from Marx's *earlier* work as influenced by Hegelian dialectics. Vygotsky was fascinated with the dynamic of dialectical materialism as it described learning and development, and *not* with the extension of that mechanic to economics or to the notion of exploitation.

Marx developed the relationship between practical activity and change during his early work whereas political recommendations were not formulated until the later phases of his writings. Vygotsky applied dialectical and historical materialism to reveal psychological development and formulated his methodology around these concepts (Rosa & Montero, 1990). “The developmental method, in Vygotsky’s view, is the central method of psychological science” (Cole & Scribner, 1978, p. 7). To this day, historicity and Marxist dialectics are used to distinguish activity theory from other sociohistorical approaches to research:

> While most sociocultural approaches acknowledge Vygotsky as their key inspiration, they typically take distance from historicity and Marxist dialectics which are foundational to activity theory, and the concept of the object of activity seldom plays a central role in sociocultural studies. (Sannino & Engeström, 2018, p. 44)

Perhaps some researchers are inconvenienced by the divisiveness that Marxism can create, but the limitations of German idealism and Marx’s modes of production were addressed in later versions of activity theory. Nonetheless, degrees of tension persist and the effort to account for them here is not novel to the literature:

> Luria (1979) remembers that Vygotsky was the chief Marxist theoretician among their study group. The severe distortions that Marxism has suffered are the reason why today many intellectuals think of it as the degraded scholasticism of Stalinism or the limited Critical Theory of Frankfurt. Both are alien to the nature of Marxism. Vygotsky’s reliance on Marx’s *Capital*, Engel’s *Dialectics of Nature*, and Lenin’s *Philosophical Notebooks* demonstrates his classical orientation to Marxism. (Blanck, 1990, p. 40)

So far, this discussion has connected tenets of activity theory intellectuals from the West, established its sociohistorical context, and discussed two defining characteristics of activity theory: historical and dialectical materialism, which can be restated to as change within a socio-cultural context.

The Hegelian dialectic. Activity theory is a sociocultural framework used to analyze human development where the unit of analysis is the collective rather than the individual (DeVane & Squire, 2012; Engeström, 2014; Jonassen, 2002). Activity theory is part of the critical tradition of historical materialism, and its philosophical roots are a blending of classical German Idealism, the writings of Marx and Engels, and Soviet Russian psychologists Vygotsky, Leont'ev, and Luria (Engeström, 1999).

Hegelian dialectics, adopted by Marx, was used to concretize practical activity as the production of knowledge. Philosophy was pulled from the ether and applied to practical human activity. Activity itself was transformative. Hegel circumscribed existence as an idealized whole with human experience characterized by the tension, separation, and fracture between the subject and the idealized object. A separation from the ideal engendered feelings of alienation in subjects and therefore motivation towards a reunification. The separation of subject from object and the resulting feelings of alienation are partially overcome by consciousness—specifically, a creative praxis, a term Marx formulated as a uniquely human quality (Gorman, 1982). Figure 10 represents a subjects' use of creative praxis to realize an object.

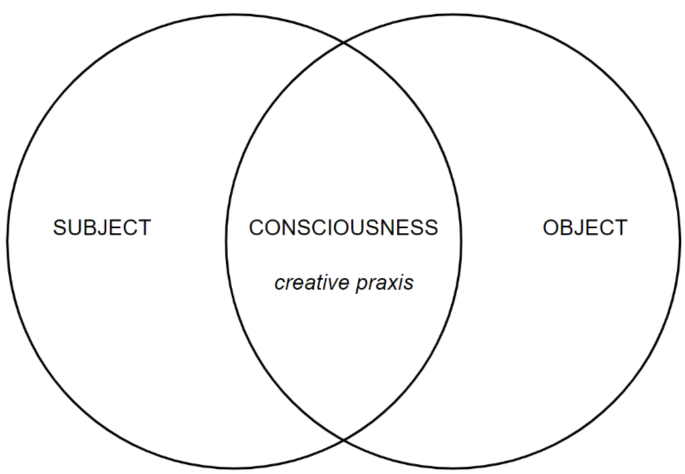

Figure 10. Union of subject and object via consciousness and creative praxis.

Hegel’s idealized version of truth proposed that truth *in all forms* was arrived at via the three moments of (a) understanding, (b) instability, and (c) speculation (Hegel, 1991). The first moment is one of understanding—when knowledge appears to be stable. The second moment contradicts the first and is dialectically oppositional. The third moment is speculative and generates new understanding that does not entirely reject the old knowledge—it is a transformation. Through this process, two forces contradict one other and morph into new forms of knowledge thesis, antithesis, and synthesis. The antithesis was the negation of the thesis, and the synthesis was the negation of the negation resulting in the creation of a new concept (Mueller, 1958). These instabilities, or antitheses, are termed contradictions and can lead to new knowledge.

Practical activity that is undertaken to reach a given objective drives or motivates, the process and activity theory describes the socio-cultural context of practical activity. This dialectical logic combined with a temporal view of activity is the core characteristic of any analysis accomplished with activity theory. Hegel’s limiting notion of truth as an idealized whole unit would be addressed by Engeström’s introduction of the expansiveness of activity systems which included notions of horizontal and vertical expansion, multi-voicedness of systems, and multiple activity systems.

Evolution of activity theory. Modern scholars describe activity theory’s phases of development over its nearly 100-year history in terms of multiple generations (DeVane & Squire, 2012; Engeström, 2014; Kaptelinin & Nardi, 2002; Roth, 2007; Yamagata-Lynch, 2010). Beginning with Vygotsky, each successive generation of scholarship enlarged and elaborated upon the unit of analysis used to describe the context of human activity—from Vygotsky’s focus on individuals or dyads, to Leont’ev’s focus on collective activity, and to Engeström’s focus on organizations, multi-voicedness, multiple activity systems, and subjectivity.

Since Vygotsky, scholars of activity theory have continued to elaborate the context of activity and how it relates to human learning and development—always embracing the interconnectedness of experience as opposed to attempting explanations of it that reduce it to its sub-components. From its beginnings, activity theory has consistently held that human activity is a mediated, sociocultural process resulting in development. It erases the distinction between research conducted in laboratory conditions and research conducted in natural settings (Denzin, & Lincoln, 2005).

Its flexibility as an analytical framework has been demonstrated in a variety of research contexts: from organizational learning (Engeström, 2001), to Human Computer Interaction (Kaptelinin & Nardi, 2002); to course design (Jonassen & Rohrer-Murphy, 1999); to design process (Cash et al., 2015); to human resource development (Tkachenko & Ardichvili, 2017); to creativity studies (Faiola, 2013); and to addictive behaviors (Koski-Jännes, 1999). Activity theory can be used on its own or in complement with other theories such as actor-network theory (Miettinen, 1999), object relations theory (Ryle, 1999) is sometimes paired with various theoretical orientations.

Vygotsky's foundational contributions. Vygotsky's key contributions to activity theory might be summarized with the following concepts.

1. Developmental behavior is mediated by many things, including tools and signs.
2. The development of higher psychological functions involves a historical and socially rooted process of internalization.
3. The zone of proximal development is a *process* and the smallest unit of human development.
4. The development of higher psychological functions can be studied using the functional method of double stimulation.

Vygotsky's sociocultural approach to human development was based upon the concept of human activity as mediated by signs and tools (Wertsch, 1991). For Vygotsky, tools serve to "conduct human influence on the object of activity" (Vygotsky, 1978, p. 55). The tool has an external orientation. But a sign is "a means of internal activity aimed at mastering oneself" (p. 55) and has an inward orientation. In this process signs emerge and recede as new knowledge is created via tool use; over time the details change, but the process remains fundamental to the activity.

Importantly, Vygotsky made no claim that signs and tools were the only mediators of human activity and "practical intelligence" (Vygotsky, 1978, p. 23). "A host of other mediated activities might be named; cognitive activity is not limited to the use of tools or signs" (p. 55). For example, "Shortly before his death, Vygotsky (1935/1994) adapted the Russian term *perezhivanie*, possibly from Stanislavsky (2007), to account for the central role of affect in framing and interpreting human experience" (Smagorinsky, 2011, p. 336). Rey (2009) relied upon Vygotsky's later work to explore the "unity of emotional and cognitive processes" and to work toward "the development of a definitions of subjectivity from a cultural-historical standpoint" (p. 59). Vygotsky's legacy hints toward further investigation into the mixture of feelings and developmental learning.

Mediation is "an essential feature of higher mental processes" (p. 45) and does not happen by "pure logic" (p. 45) but through a "prolonged process" of linked, successive, and qualitative transformation which are historical and represent the "fundamental law of development which knows no exceptions (pp. 45-46). This is the "history of behavior" (p. 46). This gradual process occurs as ideas transform through external tool use to internal orientations, as in the classic example to tying knots in a handkerchief as an aid to memorization. "When a human being ties a knot in her handkerchief as a reminder, she is, in essence, constructing the process of memorizing by forcing an external object to remind her of something; she transforms remembering into an external activity. This fact alone is enough to demonstrate the fundamental characteristic of the higher forms of behavior" (p. 51). The process is embedded in its historical and sociocultural context. The transformations involved with internalization implicate the mediating quality of reflection for learning, "For the young child, to think means to recall; but for the adolescent, to recall means to think" (p. 51) Vygotsky (1978) elegantly summarizes these ideas when he writes, "It has been remarked that the very essence of civilization consists of purposely building monuments so as not to forget" (p. 51).

The zone of proximal development was Vygotsky's model of how people learn, and the functional method of double stimulation was his model for conducting experimental research around how they learn. Vygotsky saw the zone of proximal development as a methodological tool (Garrison, 1995) for conducting developmental research into human learning. The "zone" contextualized development within a temporal (i.e., historical) context. To recall Vygotsky's (1978) definition:

> It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (p. 86)

And:

> The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. These functions could be termed the "buds" or "flowers" of development rather than the "fruits" of development. The actual developmental level characterizes mental development retrospectively, while the zone of proximal development characterizes mental development prospectively. (p. 86)

Within this framework, Vygotsky explored psychological development with a focus on human agency as observed within carefully designed experimental conditions via his method of *double stimulation* where a demanding first task (first stimulus) was paired with a neutral artifact (second stimulus) as a way of observing tool-mediated behaviors (Engeström & Sannino, 2010). For Vygotsky, psychological development must be theorized through the observation of activity within its context of accomplishment. "*To study something historically means to study it in the process of change*; that is the dialectical method's basic demand" (Vygotsky, 1978, p. 64). Also, development was conceptualized as looping and recursive, "Development, as often happens, proceeds here not in a circle but in a spiral, passing through the same point at each new revolution while advancing to a higher level" (p. 56). And so, Vygotsky conceived human development as embedded, recursive, and spiraling practical activity mediated by signs and tools within its sociocultural and historical context.

Leont'ev's collective labor and hierarchy of activity. Leont'ev was a psychologist and part of the young group of scholars working in Moscow with Vygotsky during the years before his death in 1934 (Davydov, 1995). Throughout the thirties and fifties, Leont'ev and other students continued with Vygotsky's legacy and "…laid the foundations for a formative (or teaching) experiment as an essential tool for tackling the problems of developmental teaching" (Davydov, 1998, p. 17). During this time Leont'ev operationalized the concept of *activity* and, drawing from Marx and Engels, expanded the scope of activity to include collective labor and concretized these phenomena with categories including the division of labor, rules, and community (Engeström & Miettinen, 1999). Marx's dialectical-materialist conception of activity from which Leont'ev drew, was in turn heavily influenced by classical German philosophy's idealists Kant, Fichte, and Hegel (Davydov, 1999).

It may be worth noting that the worldviews of scholars working within the tradition of activity theory do not necessarily align with those of Marx's political views: "Marx's philosophical and sociological concepts should be kept separate from his more specific economic and political views" (Davydov, 1999, p. 40). Leont'ev concretized the meaning of activity for activity theory, and nuance is lost in translation: “The concept of activity is poorly rendered by the English word; in activity theory the implication is high-level, motivated thinking, doing, and being of an individual in a given social context” (Ryle, 1999, p. 413). The foundations of activity theory connect activity with society:

> However, no matter what the conditions and forms in which man’s activity proceeds, no matter what structure it acquires, it cannot be regarded as something extracted from social relations, from the life of society. Despite all its diversity, all its special features the activity of the human individual is a system that obeys the system of relations of society. Outside these relations human activity does not exist. How it exists is determined by the forms and means of material and spiritual communication that are generated by the development of production and that cannot be realized except in the activity of specific individuals. It stands to reason that the activity of every individual depends on his place in society, on his conditions of life. (Leont’ev, 1977, p. 3)

This widened context was accomplished with the categories of community, rules, and division of labor, the use of the object-motive to distinguish one activity system from another, and a three-level hierarchical conception of dialectical activity (activity, actions, and operations). Within activity systems, divisions of labor occur when it becomes necessary for members of the group to perform different roles within the collective to realize the overall objective of the system. When this happens, there is the possibility that those individuals, in focusing on their subordinate roles, will lose their material and psychological connection to the group’s overall objective.

> Historically, the appearance in activity of goal-oriented action processes was the result of the emergence of a society based on labour. The activity of people working together is stimulated by its product, which at first directly corresponds to the needs of all participants. But the simplest technical division of labour that arises in this process necessarily leads to the emergence of intermediate, partial results, which are achieved by individual participation in the collective labour activity, but which in themselves cannot satisfy the need of each participant. This

> need is satisfied not by the "intermediate" results, but by the share of the product of the total activity that each receives thanks to the relationships between the participants arising in the process of labour, that is, the *social* relations.
>
> It will easily be understood that this "intermediate" result which forms the pattern of man's labour processes must be identified by him subjectively as well, in the form of an idea. This is, in effect, the setting of the goal, which determines the method and character of the individual's activity. (Leont'ev, 1977, pp. 6–7)

In this example, the division of labor has an obvious material effect on the system, a psychological effect on individuals now compartmentalized by their new roles, a reformulation of rules regarding how the labor is divided, and a recharacterization of the community within the system.

Leont'ev made possible the elaboration of collective activity where the object of the activity constituted the primary motive for the activity (Kaptelinin & Nardi, 2002). Participants in an activity might carry out actions related to a goal without necessarily being aware of the activity's overall object. The division of labor within the activity system may restrict certain members of the collective to specific tasks. The rule category was used to contain descriptions of cultural norms and regulations pervading the activity. The category of community was used to contain descriptions of the collective of subjects involved in work toward the object of the activity. These three additional categories expand the scope of Vygotsky's concept of the zone of proximal development to reflect the socio-cultural nature of human activity.

The primary distinguishing characteristic between one activity system and another was accomplished by the objects of activity systems and the motives of subjects to realize the given object.

> The main thing that distinguishes one activity from another lies in the difference between their objects. It is the object of activity that endows it with a certain

> orientation. In the terminology I have been using the object of activity is its motive. Naturally, this may be both material and ideal; it may be given in perception or it may exist only in imagination, in the mind. (Leont'ev, 1977, p. 6)

That the object of activity exists either as idealized in the imagination or as perceived material belies the dialectical nature of activity as theorized by activity theory. Activity systems are always defined in terms of their objects. Objects of activity systems are used to distinguish one activity system from the other.

Leont'ev introduced a hierarchical model of activity involving three levels. The general activity within a system was decomposed into actions and operations. As activities were oriented toward their objects, actions were oriented toward their goals and operations were oriented toward the conditions under which they were carried out. Self-contained, goal-directed actions were carried out in service of the larger object-oriented activity.

> The basic "components" of separate human activities are the actions that realize them. We regard action as the process that corresponds to the notion of the result which must be achieved, that is, the process which obeys a conscious goal. Just as the concept of motive is correlative with the concept of activity, so the concept of goal is correlative with that of action. (Leont'ev, 1977, p. 6)

Subjects carry out actions in service of the larger object of the activity system. Leont'ev explains how the division of labor within a society leads to "intermediate, partial" (p. 6) results for members of the collective as they carry out their constituent roles (action-goals) in service of the larger objective. For example, a member of the group whose job it is to make hunting gear as part of an activity system oriented toward obtaining food. That is, participants may or may not be engaged with actions that are directly aimed at realizing the object. In many cases, the subjects carry out complete actions that are still partial in that they do not directly attain the object.

The third level of activity is operations, which depend upon the conditions related to achieving specific goals. Once learned, operations usually become automatic and are not consciously observed. The term, operations, was taken from Vygotsky's work as it is used to describe internalization. "An operation that initially represents an external activity is reconstructed and begins to occur internally" (Vygotsky, 1978, pp. 56–57). For the hunter in the above example, the action of making hunting gear might involve repetitive cutting and stitching which have become internalized—embodied cognition, performed automatically (Bargh et al., 2012). For example, student designers in a course viewed as an activity system might perform operations as habits such as mindless research techniques or entrenched software habits; they may be unchecked assumptions about a target audience or unconscious cognitive fixations that limit perception. Although degrees of automaticity are necessary for carrying out goal-oriented actions to realize the objects of activities, "…operations in essence are only ways and means of thinking, and not thinking itself" (Leont'ev, 1977, p. 58). Operations are typically internalized forgotten routines. Alternatively, operations may be newly established routines based on newly learned actions.

The second generation of activity theory scholars carried on with Vygotsky's work after tuberculosis took his life in Moscow in 1934 when he was 38 years of age (Davydov, 1995). Leont'ev established a formalized concept of practical activity and described it within the context of a dynamic system. With this iteration of the theory, the unit of analysis was expanded to be the socio-historically connected group rather than the individual or dyad.

Activity theory hierarchy. In addition to the six components and the construct of contradictions used to describe activity systems, a three-level hierarchy of activity described the dynamics of developmental actions. Every activity system was motivated toward its object. Goal-oriented actions were carried out in service realizing the object of the activity system. Operations were constituent parts and conditional parts of actions. For example, a design course (activity system) may have a final project (object) set as the overall goal. Participants in the system might learn tools, prototype, and conduct feedback sessions (sets of actions) as work toward the final project (object.) These actions might involve habits of mind or physical repetitions (operations), often unconsciously carried out, that help to conduct the actions.

These three levels of activity are used to explain the acts of the subjects in activity systems. Across the system, a historical lens is applied. That is, the activity systems and the activities within are conceptualized temporally and socio-culturally. The framework is sometimes complemented with other theory to achieve specific research goals. For example, activity theory and action regulation theory (ART) have been used to extend the analysis of activity to more specific actions (Jones, 2012). Figure 11 is a hierarchical model of the three interconnected levels of activity carried out by the subjects within activity systems.

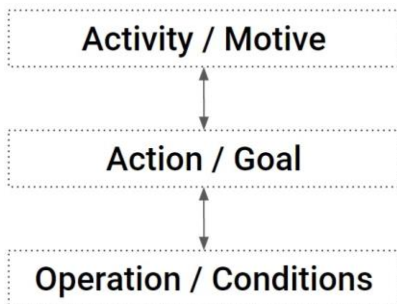

Figure 11. Activity theory’s three-level hierarchy of activity within a system. Adapted from "Learning as activity." by D. H. Jonassen, 2002, Educational Technology, 42, p. 50.

At level I the whole of the activity system is motivated by and toward its object—the final project. At level II, goal-oriented *actions* are carried out by the subjects in service of the larger object of the system. At level III are *operations*, which typically are automatic and unconsciously carried out and thus difficult to directly observe. Operations are carried out as conditionally oriented support of a goal-oriented action. This three-level structure serves to characterize the variety of actions of subjects within activity systems. Three-level hierarchical analysis of activity is used to complement the componential analysis of activity systems. The hierarchy of activity nests within and between the structural components of activity systems.

Activity theory components. All activity systems are defined in relation to their objects, and all the components operate as a dynamic system that mediates human activity. Activity systems are described using components to represent the context of activity and dynamics to represent elements of change. The components of any activity system are (a) the subjects, (b) the object that motivates the actions of subjects, (c) the instruments that mediate the actions of subjects, the (d) community subjects inhabit while working toward the object, the (e) rules that specify cultural norms and practices of the community, and the (f) division of labor that specifies how work actions/tasks are distributed among the subjects.

At the highest level, activity systems are described regarding their *objects*. Based on a shared *object*, groups and categories are used to describe activity systems. The results of developmental cycles within activity systems are *outcomes*.

Subjects are the people working toward objects in activity systems. *Instruments (mediating artifacts)* are both psychological and technical mediators. They are analogous to signs and tools and are used by subjects to achieve objects of activity systems.

The *rules* of an activity system interact with people and specify group norms and customs. The *community* is the social component of the activity and provides a social context for describing activities in activity systems.

The *division of labor* is the way in which tasks are assigned within activity systems; the *division of labor* indicates a hierarchy of power within activity systems and describe the people’s assigned roles within activity systems. In sum, these categories are used to describe activity systems, where activity is seen as a contextual, dialectical relationship between people and the world. A first step in using activity theory is to use these concepts to delineate and describe activity systems.

The dynamics of activity systems are marked by contradictions within the components, between the components, and between other activity systems. The motivational structure of subjects as they work toward smaller actions related to the achievement of the object also describes dynamics within and between activity systems.

Third generation: Engeström. Activity theory is used in a variety of applications and settings, and Engeström has arguably done the most work to represent and extend its framework. His graphic model as shown in Figure 12 has become the de facto way to represent activity systems. Engeström's work to extend and reformulate activity theory instantiated the third generation of activity theory. His work will be used as a starting point for a description of standard activity theory before progressing to his version of it.

Activity theory as analytical framework. This section explains how activity theory works. Activity theory is an analytical framework for systems-level analysis and is grounded in the sociocultural theory that resulted from the developmental research of (Vygotsky, 1934, 1978) and Leont'ev (1977). While activity theory is not a theory per se, its phenotype as an analytical framework is informed by sociocultural theory. Its framework is used to guide analysis and includes generic specifications for activity systems and the activity within those systems. There are no prescribed methods to be used with activity theory although in practice they tend to be more qualitative than quantitative. Figure 12 shows the generic, componential model of activity systems (Engeström, 2014, p. 63).

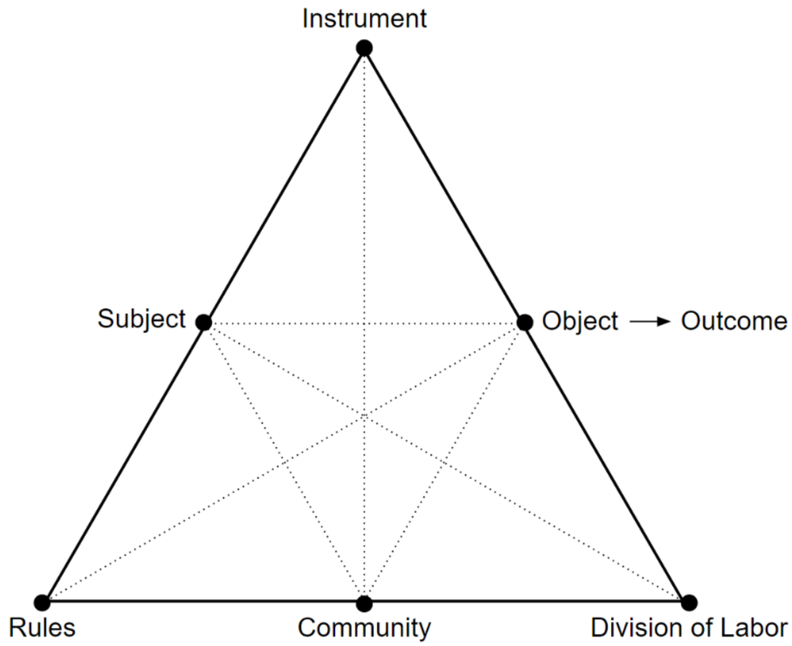

Figure 12. The structure of human activity. From "Learning by Expanding (2nd ed.)." by Engeström, 2014, Cambridge: Cambridge University Press, p. 63. Copyright 2014 by Cambridge University Press. Reprinted with permission.

Expansive learning. Whereas the structural components and hierarchical activity model are typically applied by researchers working in this tradition, the “cycle of expansive transition” is particular to Engeström and is the reason why expansive learning theory centers around the concept of the formative intervention. As opposed to research that seeks to describe and measure a phenomenon and then step away for analysis and conclusions, researchers involved with expansive learning take an active role in the learning process and design interventions that actively challenge the participants in ways that are intended to facilitate the participants-students’ learning and transformative agency. Furthermore, researchers yield a large degree of control to the context and the participants within it. The expectation is that participants take ownership of the intervention as they develop new kinds of “collective and transformative agency” (Engeström, 2014, p. xxiii).

Engeström's (2014) *theory of expansive learning* operates from three main premises. One, expansive learning is an alternative to Cartesian views of learning which tend to leave out the social context of development. For example, expansive learning aligns with learning theories that situate learning in authentic contexts and "everyday cognition" (Rogoff, Callanan, Gutiérrez, & Erickson, 2016; Rogoff & Lave, 1984). Two, it is designed around interventions that improve the lives of people. Three, it is inspired by "the discovery of cultural-historical activity theory as a potent framework for understanding and changing the world" (Engeström, 2014, p. xiv). This is different from other applications of activity theory because not all applications of activity theory involve active intervention. Some applications of activity theory involve using just its framework to analyze the components and hierarchical levels of activity systems.

Movement through an activity system is characterized by a cycle which is an elaboration of Vygotsky's method of *double stimulation,* where a problem state is introduced to subjects within experimental conditions, and next a mediating object is added to the subject's environment. Subjects may or may not be able to use the mediating object to work on the problem. Subsequent observation of how subjects make use of the mediating object reveals aspects of their thinking processes and developmental stages. So, although this cycle is particular to Engeström's work, it closely mirrors Vygotsky's method of double stimulation which involved observing how participants made use of mediating artifacts when problem-solving. The ideas of the developmental cycle and mediating objects parallel movement within a zone of proximal development. Figure 13, below, is a generic representation of a single *cycle of expansive transition* as conceptualized and modeled by (Engeström, 2014, p. 252).

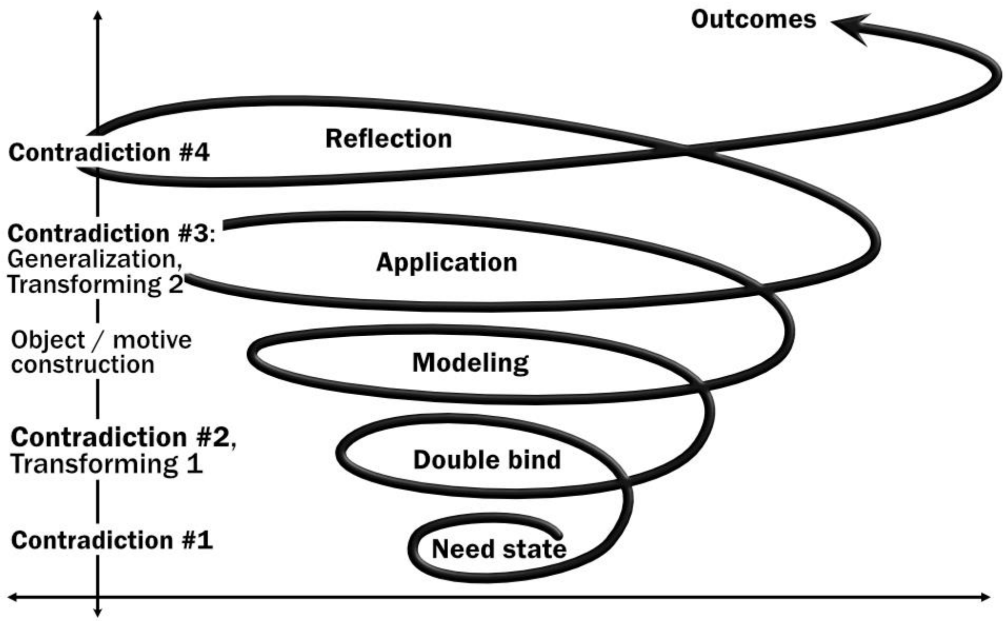

Figure 13. The cycle of expansive transition as an enlarging spiral of activity. Adapted from "Learning by Expanding (2nd ed.)." by Engeström, 2014, Cambridge: Cambridge University Press, p. 252.

At the beginning of the cycle of expansive transition, the researcher reveals some type of problem to the subject. This is termed the *primary contradiction*, and it activates a need state for the subjects. Facing this problem creates feelings of contradiction in the subjects, and they begin to think of ways to solve the problem. This part of the cycle is the double bind, where subjects are simultaneously in a need state and do not yet know what to do. This internalization of the problem is termed the *secondary contradiction*.

Eventually, the subjects will begin to try out possible solutions, and new models and hypothesis for solving the primary contradiction. At times, the researcher might provide models intended to help subjects solve contradictions. Other times, subjects will construct schemas of their own accord. Once a new and testable model or hypothesis has been formulated, subjects will apply it to see how and if it works. This part of the cycle is termed application when subjects generalize their new ideas. This new formulation of a solution is sometimes met with resistance from subjects, and a feeling of contradiction remains due to the only partially resolved dilemma.

The final part of the cycle is open-ended and characterized by a reflection on the cycle. Consolidation of knowledge is often postponed. Subjects need time to process and make sense of the activity. If the reflective process continues, consolidation can happen long after the formal cycle has concluded. The duration of an expansive cycle is expressed in weeks, months, or years. It is not intended to be a short-term intervention.

Activity theory principles. Engeström (2001) summarized activity theory with the help of five principles. The first principle is that collective activity systems are the prime unit of analysis. The second principle is the *multi-voicedness of activity systems*. Hearing all stakeholders is important for understanding activity systems. The third principle is *historicity*. The histories of actions and activities help to show their developmental process and are important for understanding activity systems. The fourth principle is the role of *contradictions* as markers of change within and between activity systems. Tensions or contradictions indicate potentials for change that might lead to the development of new instruments for learning. The fifth principle is that one full expansive cycle of development is "…a collective journey through the zone of proximal development…" (Engeström, 2001, p. 137). These categories and principles serve to guide research that uses activity theory across varying educational and workplace contexts. These principles of activity theory are summarized in Table 19.

Table 19

Five Principles of Activity Systems with Descriptions and Examples

Principles	Descriptions
First principle	Primary Unity of Analysis: collective, artifact-mediated and object oriented activity system (seen in its relations to other activity systems) • e.g., a design course
Second principle	multi-voicedness of activity systems • e.g., all stakeholders include instructors and students
Third principle	Historicity • e.g., a full cycle of learning and not an isolated incident
Fourth principle	Contradictions as sources of change and development • e.g., significant challenges in work
Fifth principle	Possibility of expansive transformations in activity-systems; 1 full cycle of expansion occurs across a ZPD • e.g., qualitatively new ways of realizing the object

Note: Adapted from "Expansive learning at work: Toward an activity theoretical reconceptualization." by Engeström, 2001, Journal of Education & Work, 14, pp. 136-137.

Bateson's levels of learning. Engeström adapted Vygotsky's zone of proximal development to be used as "the basic category of expansive research" (Engeström, 2014, p. 109). This was accomplished by the adaptation of Bateson (1972), informally developed, learning theory, which is cross-referenced with Levy's (1976) concept of the "hidden curriculum," Argyris "single-loop learning," and Schon's "double-loop learning." The historicity and contradictions inherent in Bateson's levels were important:

> First, his hierarchy is not based on observation and classification but on evolutionary and historical analysis. Second, Bateson is not satisfied with presenting the situation as a stable picture. Instead of moral pleas for "changing the situation." He probes into the inner contradictions in Learning II that generate Learning III. (Engeström, 2014, p. 112)

Engeström used Bateson's (1972) theory of learning to explain the nature of developmental progress through an expansive cycle of learning. And Bateson based his theory on contextual awareness, error detection, and corrective action which he called "learning to learn"

(Bateson et al., 1956, p. 2). Using Whitehead and Russell's (1910) *Theory of Logical Types*, each level of learning was a logical type or *class*. Therefore, learning levels were distinct, because as a logical type a class cannot be a member of itself and the member of the class cannot be a class. Progress through the levels involved discrimination between contexts via "contextual markers," error detection, and corrective action. Progression from one level to the next involved expansions in the awareness of contexts and the differences between those contexts. Between levels two and three, subjects experienced a phenomenon termed the "double bind" situation. This disconcerting feeling occurred when previously held assumptions about a level two context no longer "worked." An error was detected that could potentially lead to a "profound reorganization of character" (Bateson, 1972, p. 301) and therefore a progression to level three. For many learning contexts, "profound reorganization of character" can mean "developmental transition to qualitatively new forms of behavior" (Vygotsky, 1978, p. 33). Bateson outlines the learning levels as follows:

- *Zero learning* is characterized by *specificity of response*, which—right or wrong—is not subject to correction;
- *Learning I* is *change in specificity of response* by correction of errors of choice within a set of alternatives;
- *Learning II* is *change in the process of Learning I*, e.g., a corrective change in the set of alternatives from which choice is made, or it is a change in how the sequence of experience is punctuated;
- *Learning III* is *change in the process of Learning II*, e.g., a corrective change in the system of sets of alternatives from which choice is made. (We shall see later that to demand this level of performance of some men and some mammals is sometimes pathogenic.);

- *Learning IV* would be *change in Learning III*, but probably does not occur in any adult living organism on this earth. Evolutionary process has, however, created organisms whose ontogeny brings them to Level III. The combination of phylogenesis with ontogenesis, in fact, achieves Level IV. (Bateson, 1972, p. 293)

Level 0 learning is characterized by a specific type of response which right or wrong is not subjected to correction. There might be trial and error behavior, but it is not subject to correction. Level I learning is subject to extinction and is associated with operant conditioning and habituation. "In a word, the list of Learning I contains those items which are most commonly called 'learning' in the psychological laboratory" (Bateson, 1972, p. 288). Awareness of the context of Level I learning leads to Level II learning. For example, the child who touched the stove and through Level I learning learned to not touch the stove again is able to reapply that learning to a new, but similar context. The child visits another home, sees a different stove, recognizes the context, and does not touch the stove. Recognition of context, what it means, and corrective action (not touching the stove) is level II learning. This contextual awareness characterizes level 2 learning. Level 2 learning outcomes are habits. Frequently these habits stay in place and are not challenged and produce good results.

Double binds. However, there are times when the learned habits no longer achieve the desired result. Even when this is the case, it is not necessarily true that the learner will be aware that the learned habit caused the conflict. In some cases, this conflict will gradually manifest over time, become chronic, and create paradoxical, contradictory situations. In this case, what was working before no longer works and the learner is not entirely aware of why. The situation produces an inner conflict, and repeated experience bombards the context with contradiction. This is the phenomenon Bateson termed the *double bind*.

Learning III results when the learner realizes the learned habit or idea acquired via Level II learning is incorrect. “If Learning II is a learning of the contexts of Learning I, then Learning III should be a learning of the contexts of those contexts” (Bateson, 1972, p. 304). This point in history for the learner marks a threshold with a learner can either remain in the paradoxical state and possibly simply forget about it (until the next time) or entirely jump outside of the context. And this case the learner is seeing the context of the context and making a correction. This act results in a qualitative transformation and changes in how the learner behaves when confronted with problems in contexts that conflict with previously acquired level to learning and habits.

Bateson uses the example of a Zen master attempting to bring enlightenment to his pupil, where the master holds a stick in the air and states, “If you say this stick is real, I will strike you with it. If you say this stick is not real, I will strike you with it. If you don't say anything, I will strike you with it” (Bateson, 1972, p. 208). The pupil was put in a double bind situation because these contradictory statements occurred in a familiar context and the familiar situation became disconcerting, no longer “adding up” or making any sense. This Zen master may repeat the contradictory statements every time the pupil revisits until a Level III response is observed. For a response indicating Level III learning, the student may reach up and take the stick from the master’s hand. In this Level III response, the student went beyond the given set of information and demonstrated a qualitatively new form of behavior. The student made an abductive leap. Next, Engeström mixes Bateson’s theory of learning with existing activity theory.

Engeström recalled that activity was framed by Leont’ev’s three-level hierarchy of activity, actions, and operations that were regulated by object-orientation, goal orientation, and conditional orientation, respectively. Within activity systems, humans act through mostly unconscious conditional operations that have been learned over time. These operations are determined by goal-directed actions that are carried out by a motivation to realize the object of the activity system. They can be thought of as unconscious habits. Transformations occur through the agency and the dialectic of practical activity "…continuous creation of new instruments that in turn complicate and change qualitatively the very structure of the activity itself" (Engeström, 2014, p. 114). Transformation is preceded by a need state or problem that must be solved must be approached from within Level II learning. Contextual awareness and problem-identification distinguish Learning I from Learning II. "In Learning I, the object presents itself as mere immediate resistance, not consciously separated from the subject and instrument by the learner. In Learning II, the object is conceived of as a problem, demanding specific efforts" (Engeström, 2014, p. 118). At this point, Engeström introduced a distinction within Bateson's category of Level II learning.

Level IIa learning involves "reproductive" actions. That is, the problem is approached through repetitions of trial and error— "blind search" (p. 117). Level IIb learning involves "productive" actions—a more thoughtful approach to solving a problem characterized by a reflective pause. Engeström used examples from an observational study (Karmiloff-Smith & Inhelder, 1974) of children after they were asked to "balance [blocks] so that they do not fall" (p. 196). The researchers noted the task elicited two very different kinds of responses from the children. One was termed an *action response* involving simple trial and error actions and the other was termed a *theory response* involving "confirmation or refutation of a theory-in-action" (p. 198). Engeström likened the action responses to Learning IIa problem-solving and the theory responses to Level IIb problem-solving. Level IIb learning involved an experimental, questioning orientation where learners constructed hypothetic mental models as tools for problem-solving. Put in Vygotsky's terminology, signs are constructed by the learners and mediate their developmental process. For Engeström, this is the nature of Level IIb learning. Additionally, Schön's (1983) work involving "reflection-in-action," the "framing experiment," and "generative metaphor" were used for an analogy to Level IIb learning.

Although Learning IIb implies advanced problem-solving behavior, it does not necessarily lead to the kind of transformative learning reserved for the category of Level III learning. “Learning IIb is still typically restricted to the insightful, experimental solution of discrete, given problems…Learning IIb does not in any automatic manner imply that the context of the given problem is broken and expanded” (Engeström, 2014, p. 119).

Interestingly, this distinction has implications for the design of instruction intended to evoke experiences that might lead to Level III learning. The degree to which problems are specified for learners can direct the whole of the course experience. For example, one course design might require students choose their project topics from some list of options whereas another course design might require students to formulate project topics individually, or at least without guidance from the instruction. The former course design might be less likely to create conditions for Level III Learning than the latter, and this is because “In Learning II, the subject is presented with a problem and tries to solve the problem. In Learning III, the problem or task itself must be created” (Engeström, 2014, p. 119).

From an instructional design perspective, if learners are in situations that encourage actions like questioning, experimenting, tinkering, and pondering they may take ownership of learning and make the abductive leap to Level III. “Learning III is motivated by the resolution of the contradictions of Level II” (Engeström, 2014, p. 120). For example, student advancements to Learning III co-evolve with qualitatively new conceptualizations of self in relation to the activity (self-efficacy, agency, creative agency, creative confidence, and so on) in their ability to realize the object. Engeström explains this, “Whereas in Learning II the object is seen as a problem processing its own objective dynamics outside the subject, in Learning III the object system is seen as containing the subject within it” (Engeström, 2014, p. 120). For these students, a transformation of subjectivity occurs. They become “different people.”

> In their recent work on the historical development of human activity, Kuchermann and Wigger-Kosters (1985) argue that there is a direction: toward increase subjectivity or subjectness (*zunehmende Subjektwerdung*). This is manifested in the historical increase in the numbers and interconnections of human activities, and in the tremendous widening of the object field of those activities…I prefer to say that *activities are becoming increasingly societal*. The German word for this is *Vergesellschaftung* – a corresponding convenient English phrase is lacking. (Engeström, 2014, p. 124)

Activity theory is a socio-historical framework making the claim that deep and transformative learning requires a social component. “Learning III as the outcome and form of typically human development is basically collective in nature” (Engeström, 2014, p. 125).

In a learning community, members help each other learn. They also support each other in the navigation of double bind situations. When members of the group are confronted with difficulties, the group provides motivation and support for one another. This makes it much more likely the learners will learn to question the context and reframe it in manageable ways. Engeström adapted Bateson’s double bind concept to activity theory and learning contexts:

> In other words, the type of development we are concerned with here – expansive generation of new activity structures – requires above all an *instinctive or conscious mastery of double binds*. A double bind may now be reformulated as a *social, societally essential dilemma that cannot be resolved through separate individual actions alone – but in which joint cooperative actions can push a historically new form of activity into emergence*. (Engeström, 2014, p. 131)

In this kind of system, transformative change is seen through dual lenses of individual and group agency. Learners may carry out individual actions and work through individual double binds, but it is always against the backdrop of the group.

For Engeström, the research context should have features that present learners with ill-defined problems with no prescribed “right” path to take. Learners would need to have autonomy in their course work so that the needs and possible solutions paths are unique and appropriate to each student. This would be a way to create a need state for students that enabled personal, inner contradictions to manifest for students in a meaningful way: “Essential in the need state is that the subject faces competing alternatives and is unable to determine the direction of his or her efforts” (Engeström, 2014, p. 133). By allowing learners a high degree of autonomy in the course work, the chances that student learning experiences will be personally meaningful increase. Rather than specifying exactly how students should carry out their work, the instruction could be designed to support them with social, collaborative activities and instruction focused on high-level conceptual knowledge that is generic enough to allow each learner to fit his or her interests into the framework of instruction. “Questioning and exploding given problems and tasks, as well as generating and formulating new tasks derived from the ‘context of the context,’ that is, from the overall activity, are processes indication a transition from Learning II to Learning III” (Engeström, 2014, p. 148).

Redefining the ZPD for expansive learning. Finally, we come to Engeström’s redefinition of Vygotsky’s zone of proximal development. Engeström’s reformulation of the zone of proximal development expands it to include collective learning that is transferable to everyday situations: “It is the *distance between the present everyday actions of the individuals and the historically new form of the societal activity that can be collectively generated as a solution to the double bind potentially embedded in everyday actions*” (Engeström, 2014, p. 138).

For Engeström, if activity theory is used for course design, then the design goal should be to create transformative learning experiences for students. It would offer an inappropriate set of design guidelines for learning environments where learning goals centered around the memorization of declarative knowledge. For example, it would not be appropriate to use activity theory, as described here, when the primary activity of the course involved learners reading textbooks and completing multiple question assessments. It would be inappropriate to apply activity theory to such a learning environment.

> From the instructional point of view, my definition of the zone of proximal development means that teaching and learning are moving within the zone only when they aim at developing historically new forms of activity, not just letting the learners acquire the societally existing or dominant forms as something individually new. To aim at developing historically new forms of activity implies an instructional practice that follows the learners into their life activities outside the classroom. It also implies the necessity of forming true expansive learning activity in and between the learners. The instructional task is thus twofold: to develop learning activity and to develop historically new forms of the central activity – work, for example (of course learning activity is itself the central target activity during the early school years). (Engeström, 2014, p. 147)

A project-based learning course design would work well in this case. The course activities, however, would need to include opportunities for students to interact and collaborate with one another in some way. The course design would need to allow learners to carry out practical, real-world activities as a way of learning and development. The way activity theory is described here makes it inappropriate for the design of very short-term learning environments.

For example, activity theory would not offer a set of appropriate design guidelines for an afternoon workshop, weekend course, or one lasting a week or two. The developmental process that enables the development of new activity systems takes people time to complete, and it would be inappropriate to expect the process could be completed in an afternoon, a few days, or a couple of weeks.

> To define the entire cycle as the *basic unit of expansive learning*, and consequently of developmental instruction, means that we are dealing with learning processes of considerable length. The intensive formation of a historically new activity system within a limited community of collective (e.g., workplace, school, family, trade union) is typically a matter of months and years.

> During such a period of creation, there appear iterative transitions back and forth among the phases of the cycle. (Engeström, 2014, p. 152).

The implication here is that activity theory is an appropriate framework to use when analyzing learning and development across a few months, which is the typical length of a semester. Additionally, this means the framework would also work for longer time cycles. It could be fitted to programs that span many years and include multiple projects. This aligns with Vygotsky's (1978) description of mediated learning as a "prolonged process" (p. 45)

Creativity scholars have supported the notion that the kind of expansive developmental cycle described above can serve double duty to both create interventions that help students learn a creative design process and to provide research frameworks for the study of the creative process.

> Over the past decade, a small group of researchers has repeatedly made the argument that the frameworks originated by Jean Piaget and Lev Vygotsky to explain cognitive development in children could also be fruitfully applied to the creative process… Lindqvist (2003) argued that Vygotsky's notion of the 'zone of proximal development' might help explain how creative ideas or problem solutions take shape. (Hennessey & Amabile, 2009, p. 589)

Engeström expanded Vygotsky's zone of proximal development to include a hierarchical learning model that added more dimensions to the dialectical model of change that activity theory is built upon. He also placed it in a larger context that was more adaptable to learning environments.

Multiple activity systems. The notion of expansive learning helped address the limitations of previous generations of activity theory. Instead of constriction to a single activity system, multiple activity systems were possible for analysis. This helped address the limitations introduced at the early stages of this theory's origin with Hegelian idealism and its claim that truth is adequately represented by a bounded, "whole" and idealized system. Expansive learning theory removes these trappings on several levels. Multiple activity systems were possible for analysis. Development occurred horizontally and vertically. The systems now comprised multiple voices and concerns. The idea of holism, or that the whole system could be bounded and specified was abandoned.

Activity theory is a flexible analytical framework that works across a range of research contexts including education, organizational learning, and human-computer interactions. When Jonassen and Rohrer-Murphy (1999) used activity theory to generate design guidelines for constructivist learning environments (CLE), they demonstrated how the analytic lenses of activity theory help to explain the contextuality of operations, actions, and activities and their hierarchical relationship to conditions, goals, and motives. The authors' work suggested six steps for the design of CLEs:

1. Clarify the purpose of the activity system;
2. Analyze the activity system;
3. Analyze the activity structure;
4. Analyze mediators;
5. Analyze the context;
6. Analyze activity system dynamics. (pp. 70-77)

Elaboration of these analytic steps provided designers of CLEs with a detailed description of how to account for the dynamics between the six organizational categories supplied by activity theory. This was an example of activity theory being used for analysis and design, but not as a formative intervention.

Siyahhan, Barab, and Downton (2010) used activity theory to study the nature of play between parents and children as they engaged with the 3-D educational video game, Quest Atlantis. Findings were that although different parent-child dyads played differently from one another, outcomes were positive across all five of the parent-child pairs in the study. The authors concluded that the next iteration of the educational game should include two design changes.

Individual avatars are recommended for both parent and child to improve communication and shared intentions during gameplay. The second finding was the game scenarios should facilitate conversations around dilemmas of concern to families. Here, analysis via activity theory revealed a link between individual actions and community--and ultimately to design features that facilitated meaningful learning through play.

Engeström (2001) used activity theory to investigate the use of public health care services in Finland. The problem being addressed by the research was children's health care and the overloading of high-end services. A methodology termed "Boundary Crossing Laboratory" was used to bring together 60 participants from various professions within the children's health care system. Participants met during a total of ten sessions of three hours each. Researchers videotaped the sessions and developed that data into case studies. The intervention began with an introduction of the problem. Management presented the scientific approach to children's health care. In response, a series of video cases played showing sick children and their parents. Participants negotiated a series of "horizontal" or "sideways" moves to find and evaluate possible solutions to the problems with children's health care.

The results of the study were two new concepts about children and their parents when engaging with public health care services: *care responsibility negotiation* and *parent involvement.* Additionally, the new practice of communication between varied stakeholders continued to be a useful tool. Stakeholders continued the newly established practice to formulate another new concept and practice: *care agreement*. For this research, the main outcomes are qualitatively new instruments of expansion as represented by the newly conceived practices.

Expansive instruments: springboards, models, and microcosms. When groups or individuals encounter contradictions when attempting to achieve an objective, there is the possibility for the formation of qualitatively new instruments of development. The instrument descriptions here are elaborations of Vygotsky's concept of signs and tools. As (Engeström,

2014) describes, these instruments are found in three varieties: *springboards, models*, and *microcosms*. These new instruments have the potential to transform activity systems. Change occurs as a function of individuals interacting with the world and the world interacting with individuals. This dialectical relationship aligns with Vygotsky's concept of tool-mediated human development. As humans use tools to shape the world, the world, in turn, shapes humans. This cycle repeats and development is its result.

Springboards are often spontaneously created when people face deeply challenging problems. Springboards are not direct solutions but are hooks for making sense of new knowledge. They can be images, language, sounds, and experience that facilitate learning and the achievement of objectives. They are what is needed by the learner at the time. *Models* are used to conceptualize dynamic movement through zones of proximal development. According to Engeström (2014), "…general models are primarily needed to envision and project the evolving object and motive of the new activity" (p. 231.) In this context, models can help learners to be reflective and help researchers chart conceptual changes among learners. *Microcosms* are small, emergent, and social systems of support for learners. They are ways for learners to practice new skills socially. Microcosms are temporary supports learners use to navigate zones of proximal development. *Springboards, models,* and *microcosms* are instrumental tools subjects create and use as they work toward objectives within activity systems. These different kinds of instruments are elaborations of Vygotsky's initial idea of signs, which learners create out of necessity to achieve developmental goals or objectives.

Activity theory as a framework for formative interventions. This section will discuss the application of activity theory in research within a context of formative interventions. The origin of activity theory is the developmental research of Vygotsky, where his focus was on human learning and development within a temporal context and typically involved experimental design-based research. The roots of activity theory are firmly grounded in developmental and formative research. Davydov, (1999) was a leading Russian activity theorist and recommended four stages for using activity theory to study activity. The first stage must be accomplished before moving to the other stages and "…consists in identifying the object content of each type of activity" (p. 50). For example, if the activity system under study were a design studio, the object might be the final product students create, depending on the rules of the design studio and assuming the requirement was to create final projects.

According to Engeström (2014):

> The first step of expansive developmental research consists of (a) gaining a preliminary *phenomenological insight* into the nature of its discourse and problems as experienced by those involved in the activity and of (b) *delineating* the activity system under investigation. (p. 253)

The second stage involves creating a "morphological picture" (p. 50) of the activity structures of the collective and the individual. This can be accomplished with the help of Leont'ev's theorization of the six components of activity systems (subject-mediators-object-community-rules-division of labor) and his elaboration of activity as a three-level hierarchy of (1) activity, (2) actions, and (3) operations. The third stage involves "…the study of the emergence of the ideal plane" (p. 50). How do subjects conceive and concretize their ideas through goal-oriented actions and object-oriented activities? Using the example of a design course as an activity system, this could involve analyzing how students use prototyping actions to visualize and eventually concretize final projects. Engeström's (2014) discussion of Davydov and concept formation is useful here:

> Genuine concept formation and conceptual thinking ascend first from the perceptually concrete phenomena to the substantial abstraction, the "germ cell" that expresses the genetically original inner contradiction of the system under scrutiny. They then proceed to concrete generalization by deducing the various particular manifestation from this developmental basis. Following Hegel and

> Marx, this procedure is called ascending from the abstract to the concrete. (p. 195)

In activity systems it would be useful to investigate any successive stages of model development as evidenced by student course work.

Davydov (1999) suggested the in the fourth stage of investigating activity, "…one may begin to study significant features of activity such as awareness. The ideal as the basis of consciousness is closely connected to the system of linguistic meanings" (p. 50). This stage might involve analysis of the subjects' reflections on the activity and what it meant to them. In the example of the design studio as an activity system, this could entail conducting end-of-course interviews, gathering reflective journal data, or conducting focus groups.

Since activity theory was formulated to analyze developmental processes, it is a reasonable choice for guiding both the design and evaluation of formative interventions:

> …activity theory prioritizes formative experiments over traditional controlled experiments. Formative experiments combine active intervention in the system or processes under study with monitoring of developmental changes caused by the intervention. At the same time, activity theory does not prescribe a single method of study since different types and levels of development require different methods or combinations of methods. (Kaptelinin & Nardi, 2002, pp. 32–33)

Activity theory's generic nature and its focus on development over time make it a logical choice for investigations of the design process.

In contrast with controlled laboratory experiments, a formative intervention is carried out in situ, as in how Brown's (1992) classroom-based design experiments contrasted with her laboratory research. The change in research settings has serious implications for the formulation of research questions and the selection of methods. In the move from the rigid structures of labs to the wilderness of classrooms, researchers (and the ones funding it) trade feelings of authority, certainty, and control that laboratories engender for ambiguities, subjectivities, and nuanced contextual findings. Fair criticisms have been raised against educational research that applies the linear, fixed-input, randomized controlled trial, cause-effect methodologies associated with laboratory research to authentic contexts of human learning:

> The reputation of educational research is tarnished less by the lack of replicable results than by the lack of any deeper theory that would explain why the thousands of experiments that make up the literature of the field appear to have yielded so little. (Olson, 2004, p. 25)

This awareness of the mismatch between research goals, questions, methods, and context is not new, “Old habits of thought and long established techniques are poor guide to the evaluation required for course improvement” (Cronbach, 1963, p. 683). In the U.S., this tension has only been made worse by a narrowing scope of federal policy and research funding that increasingly favors educational research aligned with methods from the physical sciences. “Within the academy, critics of what has arguably become a dominant “scientific” orientation to education have questioned whether inquiry can—or should—be so rigidly conceived” (Ng, Stull, & Martinez, 2019, p. 2). Writing from Finland, Engeström (2011) notes the contradiction facing educational researchers caught between a need to explore new methodologies and the need to be funded:

> Educational researchers are in a bind. On the one hand, many of them recognize the limits of randomized control trials and seek ways to conduct and legitimize more practice-based and creative and theoretically ambitious research. On the other hand, there are strong administrative, financial, political, and “scientific” pressures to stick to the proven assumptions and methodological rules of positivist science. It is no wonder that many attempts at methodological innovation turn out to be weak compromises. (p. 599)

It is interesting that 83 years ago in 1936, Vygotsky’s developmental research was suppressed and some years later at the Pavlovian Conference of 1950, the work of Pavlov was elevated to the “…new official doctrine of Soviet psychology” (Rosa & Montero, 1990, p. 72).

After a critique of “so-called ‘design experiments’ that have been presented as a radical alternative to traditional experimental designs in behavioral sciences” (p. 598), Engeström (2011) described formative interventions based on Vygotsky’s principle of double stimulation as an alternative that “…builds on and purposely fosters learners’ agency” (p. 598). Formative interventions were described as following (but not limited to) four epistemological tenets:

> (a) activity system as a unit of analysis, (b) contradictions as a source of change and development, (c) agency as a layer of causality, and (d) transformation of practice as a form of expansive concept formation. (Engeström, 2011, p. 607)

Building from activity theory, this research design is characterized as a formative intervention (Engeström, 2011). Formative interventions are in the same category as “design experiments’ and “formative experiments” and the chief distinction is that formative interventions use Vygotsky’s method of double stimulation as a concrete elaboration of the zone of proximal development as the intervention studied within the research. This means that as a starting point the participants are supplied with a primary contradiction. For course design, this could take the shape of a large contradiction to introduce all subsequent course activity, such as requiring students formulate project ideas on their own, that address important social and environmental issues.

Additionally, the concept of agency is emphasized. When a research design is a formative intervention, the analysis is concerned with the development of agency within the participants. For this study, one way to evaluate the outcomes of such a course would be different measures of agency. Formative interventions are contrasted with some varieties of design experiments in that researchers do not approach formative interventions linearly. The intervention can change based on what the participants do, and the researchers do not try to control behaviors for experimental purposes. The researchers do not rigidly adhere to prespecified expectations of the outcome.

Applications of activity theory. As a generic model of human activity, activity theory is adaptable and has been applied in other fields. Research within the field of human-computer interaction (HCI) is one example (Kaptelinin & Nardi, 2002; Nardi, 1996b, 1996a; Nardi & Kaptelinin, 2006). With this application, agency was amplified along three dimensions. Biological and cultural orientations were called *need-based agency*. Assigned tasks orientations were called *delegated agency*. Actions with unintended effects were called *conditional agency*. Also, phenomenology was used to enhance sensitivity to subjectivity. Similarities and overlap with previous operationalizations of agency should be noted, specifically the three modes of agency posed by social cognitive theory: "*direct personal agency*, *proxy agency* that relies on others to act on one's behest to secure desired outcomes, and *collective agency* exercised through socially coordinative and interdependent effort" (Bandura, 2001).

DeVane and Squire (2012) discussed how researchers using activity theory "…use it as a tool for understanding learning, refining instruction, and suggesting directions for instructional design" (pp. 250-251) and "employ ethnographic data collection methods such as interviewing and observations, as well as historical methods of document gathering and analysis to understand the particulars of an activity system from multiple perspectives" (p. 250). They pointed out that "many" CHAT scholars are "…hostile to the notion of prescribing or standardizing methods for CHAT-based research, because of their deep belief that research methods need to emerge from the context being studied…the methods used have to suit both the question being asked and the context in which it is asked" (pp. 251-252). Their summary of activity theory's characteristics included five main points:

1. CHAT is an analytic tool, not a prescriptive theory that prescribes particular forms of instruction;
2. CHAT does not prescribe any particular research method, although as a theoretical tradition, CHAT methods are often deeply cultural and historical;

3. CHAT, as a research approach, is a structured and ideationally driven approach in the sense that researchers use theoretical assumptions to understand human activity;
4. Underlying CHAT is an interactionist epistemology, meaning that for CHAT researchers, learning and knowledge are inseparable from context;
5. Finally, embedded within CHAT is a conflict-driven theory of change in which evolution occurs through contradictions embedded within a system. (pp. 251-255)

These characteristics suggest activity theory is applicable to learning environments with constructivist/constructionist orientations. Since activity theory is concerned with learning as doing within socio-cultural contexts, it works for analyzing environments where people design to learn. And because activity theory employs a generic framework for analysis and a methodological orientation that tends to adjust to the given context of activity, it can adapt to a wide range of social worlds. To show the analytic utility and methodological flexibility of activity theory the authors reviewed three different cases within the learning technologies. These cases included analysis of a learning technology called the 5th Dimension, a redesign of an astronomy course to feature 3D modeling as a learning activity, and an online gaming community featuring a digital game design based upon Civilization III, a historical simulation game originally designed by Sid Meier. The authors concluded that the utility of activity theory "..lies in its ability to provide a formal grammar for understanding the 'buzzing, blooming confusion' (James, 1890, p. 462) of learning in the real world" (DeVane & Squire, 2012, p. 263).

Engeström provides an example of a formative intervention based on his research and an "intervention toolkit" called "The Change Laboratory" at the University of Helsinki. Interventions are typically done with organizations and groups that are undergoing problematic transformations in the workplace. Recordings or other documentation of the issue are brought into the lab.

Participants are shown these representations of the problem, and this is called the first stimuli. After data representing the problem is identified and gathered, it is then used to conduct the first session and provide the first stimuli. Next, researchers introduce the second stimuli which involve conceptual tools that participants can use to work toward a resolution. These second stimuli are typically triangular models of the activity system. Participants use these materials to work out solutions to the identified problem or contradiction. Theoretically, participants should be able to transfer the learned process to other issues that arise in the future.

Barab et al. (2002) used activity theory and its construct of contradictions and tensions as an analytical framework for exploring how students' participation in the Virtual Solar system (VSS) project mediates learning of scientific knowledge. The VSS was an experimental course offering constructive approaches to learning astronomy. Virtual reality environments and 3D modeling activities replace traditional lecture-style courses in astronomy. Their initial analysis for systemic tensions within the activity system involved data set including field notes, interview data, pre-post interviews, and database logs. Data revealed a tension between the need to learn astronomy and the need to learn how to operate VR models. A second tension was discovered between the expectations of learners and instructors regarding course design. "Specifically, it is the tension between teacher-centered, prespecified instruction on one end and student-directed, emergent learning at the other end" (Barab et al., 2002, p. 86).

Their findings included design guidelines for improvements of the course through the identification of contradictory forces within the categories of activity theory. Instead of eliminating either of the opposing forces, the goal is to achieve a balance between them. For example, the balance between students as passive recipients of knowledge versus students as active creators of knowledge is important to maintain, according to the interview data. Also, a balance was important between the need to understand how to use digital learning tools versus the need to learn the course content, astronomy. The opposing pieces of each contradiction form a continuum which can inform future course design.

This research was guided by a general methodology the researchers describe as "naturalistic inquiry" (Barab et al., 2002, p. 83). Activity theory's categorical structures and the construct of systemic tension or contradictions within and between activity systems were used to generate design guidelines based on a mixture of qualitative and quantitative data.

Detlor, Hupfer, and Smith (2016) used activity theory to research a digital storytelling initiative implemented by two Canadian libraries. Categories of activity systems are used to analyze and describe the digital storytelling initiatives, while contradictions within and between activity systems provide additional layers of understanding. This research was part of a larger plan to extend the research project to other local and non-local digital storytelling initiatives. This application of activity theory is limited to the description of the activity system and contradictions. This may be due in part to the limited historical data used for the research.

Considering the importance of *historicity* to activity systems (Engeström, 2001), this research would be stronger with a more robust application of activity theory. According to Engeström, "Activity systems take shape and get transformed over lengthy periods of time. Their problems and potentials can only be understood against their own history" (p. 136). The historical development of activity systems over time is key to understanding them. For activity theory, the *historicity* of activity systems is a fundamental category for analysis.

In the effort to develop a multi-scale instrument to explain and describe the design process, (Cash et al., 2015) used the three-level hierarchy of activity to analyze engineers' design process. Three engineers were observed in their work environment using video cameras. The researchers adapted three level hierarchy from activity theory (activity – actions – operations) to the engineers' design process and assigned various design processes used by engineers to the various levels, relabeling those levels as macro-scale, meso-scale, and micro-scale. Because operations are often performed at the unconscious level, this category was removed, and tasks were substituted, leaving a three-level hierarchy consisting of activities, tasks, and actions.

In parallel with activity theory's three-level hierarchy of activity, activity was the overall object-oriented acting, tasks were goal-oriented actions, and actions were discrete parts of the tasks. The macro-scale was called the concept development process and "sequences of activities linked by a common focus, e.g., coordinating the design work of a team across the development of a new product" (p. 5). The meso-scale was called the ideation process and "sequences of tasks linked by a common motivation, e.g., distribute research and development findings to the design team" (p. 5), and the micro-scale was called the communication process and "sequences of actions linked by a common goal, e.g., compile a design report" (p. 5). Two coders coded a small piece of video until 100% agreement was reached at which point the schema was finalized. They generated a coding schema based on the literature and Table 20 shows these levels, the corresponding levels from activity theory, and the engineering processes within each categorical level.

Table 20

Code Scheme or Multi-Scale Analysis of the Design Process

Code scheme for multi-scale analysis of design activity		
Level I	Level II	Level III
macro-scale processes	meso-scale processes	micro-scale processes
product design	ideation	finding within source
organizational information processing	concept development	finding source
personnel management	design elaboration	interpreting
	reviewing	
	technical embodiment	
	testing	
	project reporting	
	information seeking	

Code scheme for multi-scale analysis of design activity
dissemination

Note: Adapted from "Activity Theory as a Means for Multi-Scale Analysis of the Engineering Design Process: A Protocol Study of Design in Practice." by P. Cash, B. Hicks, and S. Culley, 2015, Design Studies, 38, pp. 1-32.

Three engineers were observed working on design problems through a one-week duration. Findings resulted in recommendations for future research and the observation that the design process was interlinked and therefore stage design models could potentially be misleading for those trying to teach design, and that support for all stages of design should be provided through the full duration of a given design project. Speculations were offered about the possibilities for universal analysis of the design process using similar multi-scales.

Crawford and Hasan (2006) used activity theory to develop a research strategy to investigate information systems. They used the structural components of activity theory to present five vignettes to assess different ways in which activity theory could be applied to information systems research.

This resulted in an organized way of reporting across multiple research projects using seven headings derived from activity theory. Those headings included (a) the object of the research activity, (b) the subjects involved, (c) the purpose and motives guiding the activity, (d) the tools used by subjects to accomplish the activity, (e) the culture surrounding the activity, (f) the tools used by researchers, and (g) the research intervention and evolution. The five different research projects involved a Q-study to investigate differences in use search strategies, the use of a knowledge management systems by managers, collaborative online work environments, cooperative online gameplay and analysis of online group interactions.

The researchers concluded that "Activity theory provides a comprehensive, holistic and dynamic analytical framework that, in our opinion, is ideally suited as a secondary tool for research" (Crawford & Hasan, 2006, p. 65). The example involved a straightforward use of activity theory as an analytic framework to compare and assess multiple research projects in a consistent way.

Use-inspired basic research. When activity theory is used as a formative intervention, or as the practice of expansive learning, it falls within the category of use-inspired basic research. This concept was developed by Stokes (1997) with his critique of the false dichotomy between basic and applied research. Stokes (1997) traced the roots of the schism to the birth of scientific inquiry, the Greek civilization, and its cultural norms, which relegated the practical arts and physical labor to those of low status in the community (i.e., slaves). These beliefs laid the foundation for an ideology that was canonized in Plato's *Republic*, persisted throughout history into modern times, and was responsible for the institutional separation of pure and applied science in the first German universities of the 1800s—which was further entrenched by the German idealists' preference for pure inquiry. The paradigmatic German university system, in turn, fed the roots of the university system in American culture, which replicated the separation of basic and applied science. This division of labor was institutionalized in the United States, with American research universities serving as intellectual hubs for pure science and American corporate industry serving as labs for applied research.

This separation of theory from practice led to contradictions and systemic tension within and between the federal government, research universities, and private industry after WWII. America invested heavily in science during the war, and its universities, previously reliant upon private sponsorship, began to receive federal funding. Instrumental in organizing and allocating funds for scientific research under President Roosevelt's wartime administration was Vannevar Bush, who envisioned an elite cadre of scientists spearheading technological innovation. When the war concluded, Bush attempted to shape funding policy in line with his vision and was increasingly met with resistance by a Congress that took issue with such allocation of power to a small, elite group of scientists. History had demonstrated the value that could be realized from research that integrated theory and practice. The Greek culture that birthed the fractured research system nonetheless held one clear example of an activity that combined pure inquiry with practical application in the work of the Hippocratic physicians. During the European Renaissance, Bacon conducted goal-oriented utilitarian research that blended practice with science while aiming for the public good. Stokes used Pasteur's work as an example of use-inspired basic research. More contemporary examples were innovative American corporations such as Bell Labs and Rand Corporation that combined scientific research with considerations of use.

Broadly speaking, use-inspired basic research manifests under a variety of different interventions described as action research, co-operative design, design experiments, design-based research, design experiments, formative interventions, formative experiments, generative design experiments, participatory action research, and participatory design. All these intervention styles of research are characterized by researchers who are actively involved in the activity and do not take a passive role in the research, as opposed to more conventional research involving a dispassionate approach focusing strictly on the refutation of hypothesis and measurement of phenomena. Some of the earliest examples of this kind of research can be found in the work of Brown (1992) and Bφdker, Grφnbæk, and Kyng (1995).

Conclusion

This chapter has reviewed creativity, design, and activity theory as a way of setting the stage for research into creative design ability. Creative design is a complex process that requires time and space to develop. Project-based learning has been shown to engage student interest and sustain motivation across a wide range of subject matter. Design methods, particularly design thinking, offer promise for scaffolding students' design process and providing instructors with guidance for implementing project-based courses. Assessment of project-based learning and creativity is accomplished differently than in traditionally designed learning environments. Developing creative design ability has as much to do with attitudes and process that it has to do with declarative knowledge. Viewing development from a systems perspective seems to align with the multidimensional nature of creative design ability.

Activity theory was identified as a framework well-equipped for analyzing creative design process as its systems orientation is sensitive to contextual elements in multiple dimensions that shape learning and development. Activity theory has also been used to design formative interventions intended to strengthen participants' agency within an iterative and researchable framework (Sannino et al., 2016). Activity theory, expansive learning, and formative intervention research hold promise for the research and development of a wide range of learning environments. With this knowledge, course designs can be improved, assessment practices can be improved, and future research can be focused within areas that emerge as most germane to student development.

An initial strategy for exploration of a project-based course and identification of contextual factors that influence design creativity within it involved connecting with pre-existing literature from the creativity and design domains. An awareness of this literature might aid the recognition of their evidence (i.e., previously identified aspects of creativity and design) in the course activity system.

Table 21 summarizes the main constructs identified by this review of the creativity and design literature. These constructs were used to generate the codebook in Appendix A to guide the analysis of data collected within a course activity system where participants worked to design and create individual final course projects. Also, the five design thinking factors identified by (Blizzard et al., 2015) were elaborated with findings from the creativity and design literature, which served to integrate the mixed methods used for this study (i.e., the Blizzard et al., (2015) design thinking survey instrument with qualitative content analysis of design journal and interview data.)

Table 21

Key Terms for Creative Design in Review of Literature

Key terms for creative design	Related literature
Blizzard et al. 2015 - five survey factors augmented with more detailed sub-themes	
1.0 Feedback seekers	(Blizzard et al., 2015)
1.1. Empathy - human-centeredness	(Brown, 2008; Kouprie & Visser, 2009)
2.0 Integrative thinking	(Blizzard et al., 2015; Brown, 2008)
2.1 Framing	(Schön, 1983; Dorst 2015; Runco, 2015)
3.0 Optimism	(Blizzard et al., 2015; Brown, 2008)
3.1 Creative confidence	(Kelley & Kelley, 2013)
4.0 Experimentalism	(Blizzard et al., 2015; Brown, 2008)
4.1 Questioning	(Brown, 2008; Smith, 2011)
4.2 Problem finding	(Jia et al., 2017)
4.3 Divergent thinking	(Guilford 1959; Baer, 1996; Runco & Acar, 2012; Simonton, 2012)
4.4 Convergent thinking	(Cropley, 2006; Simonton, 2015)
4.5 Prototyping	(Gero 1990; Brown, 2008)
5.0 Collaboration	(Blizzard et al., 2015; Brown, 2008)
Additional constructs	
Abductive design reasoning	(Cross, 1999; Kolko, 2009; Dorst, 2011)
Co-evolution of problem-solution	(Dorst & Cross, 2001)
Playful attitude - fun - excitement	(Bateson & Martin, 2013; Runco, 2007; Davis, 1999; Rieber, Smith, & Noah, 1998; Vygotsky, 1933; Dewey 1910)
Feelings of surprise	(Dorst & Cross, 2001; Goslin-Jones & Richards, 2018; Smagorinsky, 2011)
Locating and using resources	(Razzouk & Shute, 2012)
Project management	n/a
Psychological safety	(Amabile, Barsade, Mueller, & Staw, 2005; Cramond, 2005; Davis, 1999; Rogers, 1954)
Time management	n/a
Tolerance of ambiguity	(Zenasni, Besançon, & Lubart, 2008)
Five-factor personality model	(Digman, 1990; Goldberg, 1993)
Everyday creativity	(Richards, 2010)
Unconscious creativity	(Bargh & Morsella, 2008; Bargh, Schwader, Hailey, Dyer, & Boothby, 2012)

Physical setting and creativity	(McCoy & Evans, 2002; Thoring, Desmet, and Badke-Schaub (2018)
Assessment of product creativity	(Amabile, 1982; Amabile & Pillemer, 2012)
Incremental and radical creativity	Norman and Verganti (2014)
Discovery orientation	Csikszentmihalyi and Getzels (1971)
Organizational creativity	Puccio & Cabra (2010)
Hard and soft systems methods	(Broadbent, 2003)
Wicked problems	(Rittel & Webber 1973)
"Designerly ways of knowing"	(Cross, 1982)
Problem types	(Jonassen, 2011)
Models	Morrison and Morgan (1999)
Schemas	Gero (1990)
IDEO design model	IDEO website
d.school design model	Stanford d.school website
British Council “double diamond” design model	(Design Council, 2019)

CHAPTER 3

METHODOLOGY

Research Questions

The purpose of this study was to explore how creative design ability developed for undergraduate students as they identified and solved everyday problems. The primary research questions were:

1. How does creative design ability develop for an interdisciplinary group of undergraduate students as they identify, design, and deliver final projects to solve everyday problems?
2. What contextual elements facilitate the development of creative design ability?
3. What evidence of creativity and design thinking exists in students' developmental process?

Mixed-methods Exploratory Design

This study used a sequential exploratory (Stebbins, 2001), mixed-methods design. The unit of analysis was a 15-week undergraduate course where students were required to identify, design, and deliver final projects on the final day of classes. The primary data sources were (1) participant design journals, (2) participant interviews, and (3) a pre/post design thinking traits survey. Activity theory (Engeström, 2014; Jonassen, 2002) was used as an analytical framework to describe the course as a system and the contextuality of its data. Thematic analysis was used to identify themes and generate codes from participant text (Braun & Clarke, 2006; Mann, 2016). Qualitative content analysis (Morgan, 1993) was used (a) to assign, count, and rank order codes by frequency and (b) to interpret the code rankings. A t-test was used to compare pre and post-survey results. Outputs of the study fit in the following two categories: (a) theoretical perspectives with suggestions for future research and (b) proposals for course design, implementation, and assessment. Figure 14 summarizes the research questions, data sources, and methods of analysis.

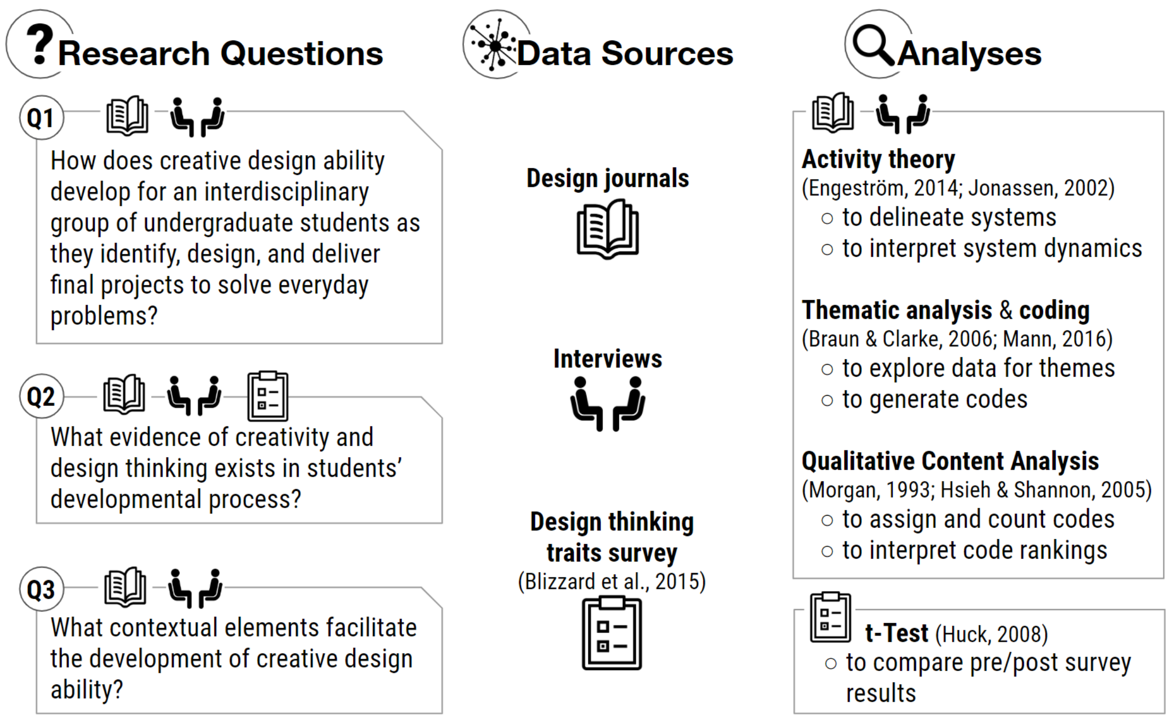

Figure 14. Research Questions, Data Sources, and Methods of Analyses

The Course as an Activity System

The following paragraphs describe the course in terms of the components of an activity system. These components are as follows: subject, instruments, rules, division of labor, community, object, and outcome.

The unit of analysis for this study was a 15-week semester upper-level elective course offered to undergraduates at a major university in the southeastern United States. The course was comprised of two sections. Each section met face-to-face for one hour and fifteen minutes twice a week. The main requirement of the course was for each student to choose a personally meaningful project topic that would serve as the focus for the semester's work to design and deliver final prototypes of the project ideas. The course began on August 14, 2018, and concluded with a final showcase event during the last day of class on November 29, 2018.

The classroom was well-equipped and provided handicap accessibility, climate control, abundant overhead lighting, reconfigurable furniture (desks, chairs), whiteboards, Smart Boards, Wi-Fi access, and some natural lighting with several windows spanning one side of the room. Figure 15 is a picture of the classroom.

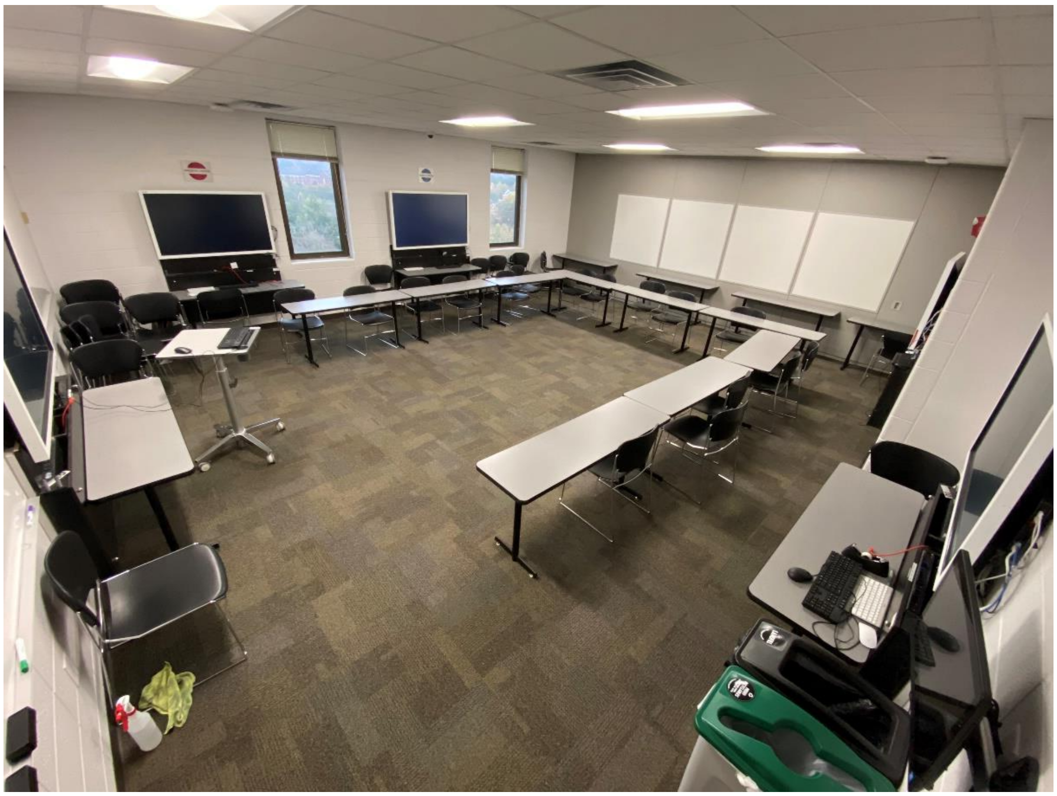

Figure 15. Classroom for the course

Figure 16 was adapted from a graphic provided by Engeström (2014) and represented the course as an activity system.

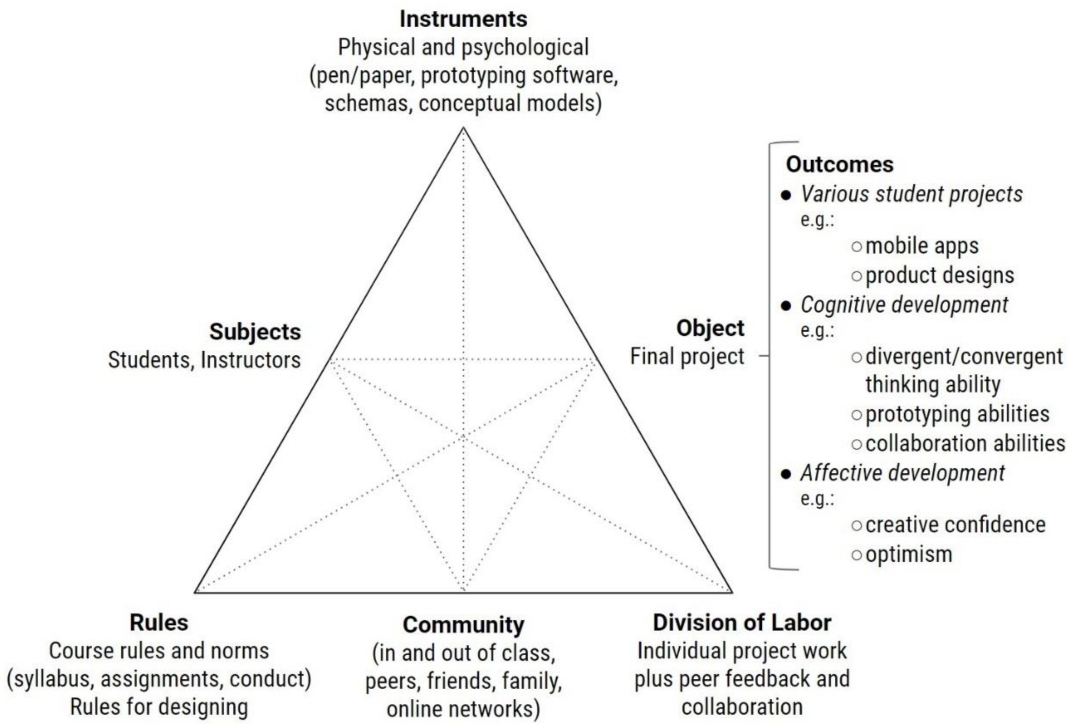

Figure 16. The course represented as components of an activity system. Adapted from "Learning by Expanding (2nd ed.)." by Engeström, 2014, Cambridge: Cambridge University Press, p. 63.

The *subjects* in this activity system were the student participants and the instructor participant. There were 25 student participants in this study, although there were 28 total students enrolled across both sections of the course. Three students did not provide informed consent, and therefore, no data from these students were used or included in any aspect of this study.

Twenty-two of the 25 participants reported demographic information. Within this group of 22 participants, age ranged from 19 to 25 years, and most students were between 21 and 22 years old. Participants ranged in college-level from sophomore to senior, and most participants were seniors. Two students were 19 years old, four were 20 years old, seven were 21 years old, five were 22 years old, three were 23 years old, and one was 25 years old. Two students were sophomores, five were juniors, and 15 were seniors. There were 9 females (41%) and 13 males (59%). Student participant demographics are displayed in Figure 17.

Student Demographics (N = 22, 3 not reporting)

Age

25 (1)
23 (3)
22 (5)
21 (7)
20 (4)
19 (2)

Major

- accounting (2)
- biology (3)
- communication sciences & disorders (3)
- consumer journalism (1)
- finance (3)
- management information systems (4)
- mathematics (1)
- mechanical engineering (2)
- political science (1)
- psychology (1)
- risk management and insurance (1)

College level

Seniors (15)
Juniors (5)
Sophomores (2)

Gender

Female (9)
Male (13)

Figure 17. Participant demographic data

The participant group was interdisciplinary, and there were 11 student majors represented in the group. Four students were management information systems majors, three were biology majors, three were communication sciences and disorders majors, three were finance majors, two were mechanical engineering majors, two were accounting majors, one student was a consumer journalism major, one student was a mathematics major, one student was a political science major, one student was a psychology major, and one student was a risk management and insurance major. Participant demographic data is also provided in Appendix B.

The instructor was a doctoral student in his third year of course work and conducted his own informal research into creative design. His studies focused on creativity, design thinking, and how to support those abilities in learning environments. His scholarly interests were in facilitating students creative design thinking using magic performance, especially on reducing design/cognitive fixation. He retained the overall course structure and design used during previous semesters of the course when I was the instructor. He added his own in-class activities intended to support students' creative design process.

The activity system component of *instruments* was derived from Vygotsky's constructs of *signs* and *tools*. Signs were used as abstract psychological tools such as schemas and mental models of creativity theory and design thinking methods. Tools were used as concrete instruments such as physical and digital materials in the form of paper prototypes and design software. Data from design journals, interviews, and surveys suggested 21 unique tools across 11 categories were used for creative design work. Tool categories included 3D editing, animation building, video editing, image editing, computer languages and frameworks, design prototyping software, conventional prototyping materials, and online learning materials. The complete list of tools participants reported using is in Appendix C.

Signs were not as straightforward to detect and required indirect means of measurement and inference. Existing and emerging mental models were inferred by coding emergent design methodologies used in project work. Signs were grouped into cognitive and affective categories. Examples of cognitive signs were the codes *prototyping* and *tolerance of ambiguity*. Examples of affective signs were *feelings of surprise*, *optimism*, and *creative agency*. Affective signs differed from cognitive signs in that cognitive signs were skill-oriented, and affective signs were oriented as affective states associated with challenges, actions, goals, and accomplishments. The codebook in Appendix A describes each code and differentiates between action, which includes cognitive abilities, and affect. Cognition and affect were not intended to be mutually exclusive categories as the related constructs are blended in practice.

The *rules* included course norms and rules provided by the instructor and were described for students in the course syllabus, which is in Appendix D. Required in-class activities involved students' sharing tool experiences, sharing project ideas, sharing prototypes, giving and receiving project feedback, and instructor-led presentations of material. Rules also included cultural norms such as students' tacitly held beliefs about creative design and were demonstrated by how the instructor modeled attitudes and methods for accomplishing project work learned from the study of creativity and design thinking.

Students earned grade credit for their coursework across four main areas. These areas were participation (25%), readings and reflections (15%), tool use reporting (15%), and final project work (45%.) The student design journal entries that provided data for this research were part of the normal course work. The series of four design journals was worth a total of 10 of the 100 possible points students could earn in the course. Students earned full credit for the completion of the journal entries. That is, journal entries were not graded for their content, but only for their completion.

The *division of labor* involved how work was divided and distributed for participants' work toward their final projects. The division of labor was minimal because all the students worked on individual projects from design to delivery. This was because the course rules reflected a constructionist epistemology (Bers, Ponte, Juelich, Viera, & Schenker, 2002) and because students were granted high levels of autonomy in their course work. The instructor supported students in their efforts to work within this kind of structure and to be self-directed in their work. This kind of division of labor was a key design feature of the course.

The rules and division of labor helped to define the *community*, which included those whom students brought into their project work from outside of the course—such as friends, family, or online networks. The in-class community was interdisciplinary, and a wide range of majors, interests, and project topics were represented. Community interactions during class were the norm for course activity. Much of the in-class activity was oriented around sharing design prototypes, sharing tool experiences, and giving and receiving tooltips and design feedback on peers' design prototypes. Community activity was substantially defined by these project-related actions and grew to be a general learning resource for students and the instructor of the course.

Activity systems are defined by their *objects*. The object for this system was the individual student project. Each student was responsible for generating an original final project idea that would serve to direct coursework. Any project idea was supported if it could be designed, prototyped, and presented in class. While student projects and learning paths were unique, the common object of a final project served to unify student activity.

The assignment details for final student projects were intentionally general so as to allow students a high degree of autonomy in choosing what their project work would entail. Throughout the course, the students and the instructor communicated with each other to negotiate project details on a per-student project basis. There was no formal printed list of requirements for the project, and students were made aware of the requirements verbally in class. The instructor provided the following description:

> The requirement for the final project assignment is very general. All of the students in the class need to design a logo or app icon for their product. For students who chose app design, they are required to finish all the main function modules, as indicated by the conceptual map developed in the middle of the semester. At least, they need to have a homepage, login/register page, and main function page. For students who chose 3D printing, the requirement is attending the 3D printing workshop and get their 3D product printed in Makerspace. Before the final showcase, I talked with every student in the class and let them know which part of their project needs to be improved. (Course instructor, personal communication, September 1, 2019)

The *outcomes* varied for each student and included the delivered projects, cognitive development, and affective development. In addition to project deliverables, outcomes were qualitative transformations (e.g., cognitive and affective) in the way participants accomplished creative design. These outcomes were characterized by new ways of thinking about and practicing creative design methodologies. It is possible development continued after the study concluded since participants may have reflected upon and practiced what they learned after they completed the course.

The most common project topic category was recommendation engines and the most common deliverables were mobile app designs. Table 22 summarizes participants' project characteristics. This data provided supplemental information for the primary data used in this study. Appendix E provides a table that adds student majors and tools used for their project work.

Table 22

Participant Projects

Project name	Project design	Project category	Description
Mop Socks	product + app	cleaning supplies	gamified cleaning tasks
FreeBoard	web app	communications	forum design
Ti-dx	product	computing devices	specialized calculator
Earfones	product	device accessories	cord management
ModStand	product	device accessories	phone accessory/clamp
Ultimate Trivia	mobile app	education	trivia game
Solar Tree	product	energy	solar device
Opposed piston engines	product	engineering	auto engine
PT (Personal Trainer)	mobile app	exercise	fitness training
Froomie	mobile app	housing	roommate finder
The Stabilizer HQ	product	medical	medical implant
Ez-slide	product	musical equipment	guitar accessory/glove
Travel Easy	mobile app	recommendation engine	travel guide
Shuttle bus?	mobile app	recommendation engine	bus finder
Spot	mobile app	recommendation engine	parking finder
Park Buddy	mobile app	recommendation engine	parking finder
Where Should We Eat?	mobile app	recommendation engine	restaurant recommendations
College Buddy	mobile app	recommendation engine	college search
UGA Parking app	mobile app	recommendation engine	parking finder
ShoeMe	mobile app	recommendation engine	retail shopping/shoes
BPMusic	product w/ app	recommendation engine	music selections
Garden Guru	mobile app	recommendation engine	garden planner
Unwritten	app + web site	software design tools	fiction generator
Between Bikes	product w/ app	transportation	smart bike lock
SMART Park	product w/ app	transportation	parking finder

Design of the Course

The course was project-based (Blumenfeld et al., 1991; Condliffe, 2017; Edutopia, 2001) and its design was informed by the theoretical perspectives of constructionism, situated cognition/situated learning, and self-directed learning—as described by Clinton and Rieber (2010) and especially with regard to the freedom in choosing any project topic, which was a primary characteristic of the first of three sequential courses in the studio experience.

The course design afforded students a high degree of personal autonomy in their project work. Student efforts were supported with in-class activities that involved technical design tools and conceptual design tools such as creativity-building and design thinking methods. The instruction was complemented by the instructor's innovative ways of modeling creativity and design thinking concepts through the performance of magic. The instructor was an exceptionally skilled magician who blended magic demonstrations with pedagogy by performing and decomposing magic tricks to emphasize aspects of the creativity and design literature. These demonstrations were intended to challenge and inspire students to approach design work creatively. He also shared the principles used by magicians in designing their magic performance with students. He encouraged students to apply these principles learned from magicians to the design of their own projects. Most of the class time was occupied by authentic hands-on activities oriented towards tool use and prototyping.

The syllabus stated the main learning goals of the course, which are listed below.

- Develop skills and confidence in generating and refining creative ideas.
- Apply creative design thinking to the personal design process.
- Be able to find and use tools to realize design ideas.
- Develop skills in demonstrating and communicating design ideas.
- Become an independent learner.

Table 23 shows the primary in-class activities and homework assignments of the course and their arrangement across the 15-week course length. The syllabus is in Appendix D, and a per-class listing of topics and activities is in Appendix F.

Table 23

Course Activities and Assignments

Course activities	Idea Generation creativity & design thinking					Design refine & develop ideas					Testing & delivering				
Week #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
In-class activities															
Sketching		*	*	*	*	*	*	*	*	*	*	*	*	*	*
Journaling			*				*						*		*
Mind mapping			*	*	*	*	*	*	*	*	*	*	*	*	*
Concept mapping			*	*	*	*	*	*	*	*	*	*	*	*	*
Journey mapping				*											
Design tool presenting				*	*	*	*	*	*	*	*	*	*	*	*
Video creating				*				*		*					
Idea presenting					*	*	*	*	*	*	*	*	*	*	*
Prototyping					*	*	*	*	*	*	*	*	*	*	*
Peer feedback							*	*	*	*	*	*	*	*	*
Digital prototyping								*	*	*	*	*	*	*	*
Assignments															
Reflection		X													
Design journal 1			X												
Journey map				X											
Creative design guideline				X											
Design journal 2							X								
Tool report 1 10/18										X					
Design journal 3													X		
Tool report 2 (optional)															
Final project															X
Design journal 4															X

Activity theory provides an additional analytical perspective on this course design as an expansive developmental cycle (Engeström, 2014; Sannino et al., 2016). Figure 18 shows course activity through a 15-week cycle of expansive transition and represents an expansive developmental cycle within the context of the course. The graphic below adds an outward and upward expanding spiral to represent the developmental cycle of the activity system and was based on the cycle of expansive transition model proposed by (Engeström, 2014, p. 252).

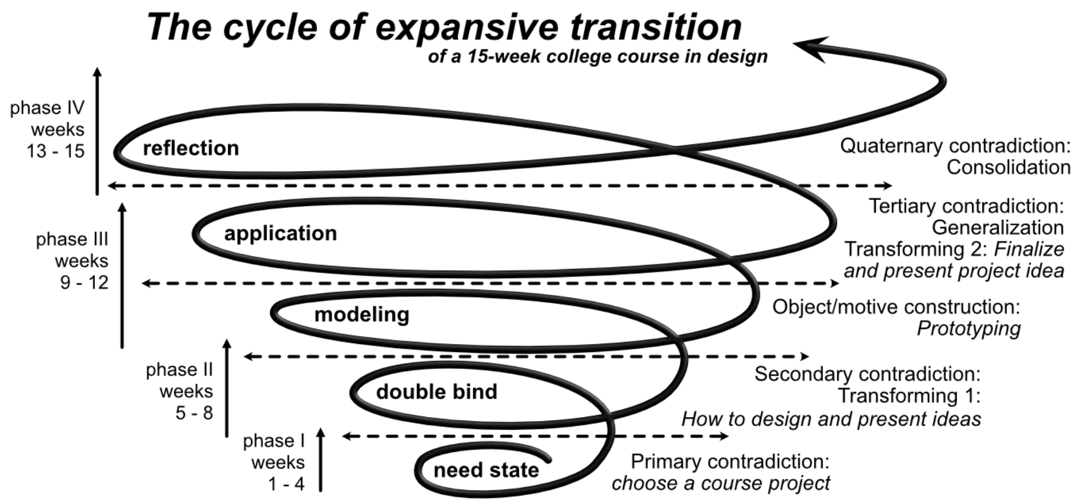

Figure 18. The cycle of expansive transition facilitated by a college course in creative design, Adapted from "Learning by Expanding (2nd ed.)." by Engeström, 2014, Cambridge: Cambridge University Press, p. 252.

The cycle began with the initiation of an ambiguous, ill-defined need state. Students were required to independently choose course projects that would direct their project work for the semester, and this introduced the primary contradiction for each student. Contradictions were an important part of the coding scheme used to analyze data in this study. Next, potential double bind situations emerged for students. Neither the instructor nor the course materials offered directives for what project topics should be, and students were challenged to stand and present their project choices to the class. This instantiated the secondary contradiction for students as they transitioned from generating project ideas and to the challenge of making their unique ideas concrete enough to coherently present in class. Approximately four weeks were available for completing this phase of the cycle.

After project topics were established, students began the practice of modeling their project ideas through prototyping actions. Prototyping involved the construction of multiple shared project iterations, which were supported by peer feedback. Learning to use design tools occurred in tandem with prototyping actions. Around four weeks were allotted for learning to prototype and learning to use a range of prototyping tools and methods. The next four weeks involved creating higher fidelity prototypes and presenting more developed versions of project ideas.

Simultaneously, students and the instructor continued to engage in giving and receiving feedback on design ideas. The instructor consistently explicated concepts supporting creativity and the various tools and methods associated with design and design thinking, which included regular modeling of how to give and receive feedback on design prototypes. The instructor's behaviors and attitudes supported a class atmosphere conducive to creative expression. These actions culminated with a final project day when students were required to present their individual projects in a public showcase. The showcase occurred in the regular classroom at the regular class meeting times, and members of the public were invited to attend. The last phase of the cycle involved reflections that were encouraged by a final reflective journal entry.

Data Collection

I introduced myself and my research to students during week two of the course and made it clear their grades would not be affected in any way if they decided not to participate in the study. The course instructor reiterated this fact to the students. I then distributed informed consent forms and the first survey to the prospective participants.

Data collection spread across one 15-week semester. A one-week holiday break was not included in the description of the 15-week course design. The data collection schedule is shown in Figure 19.

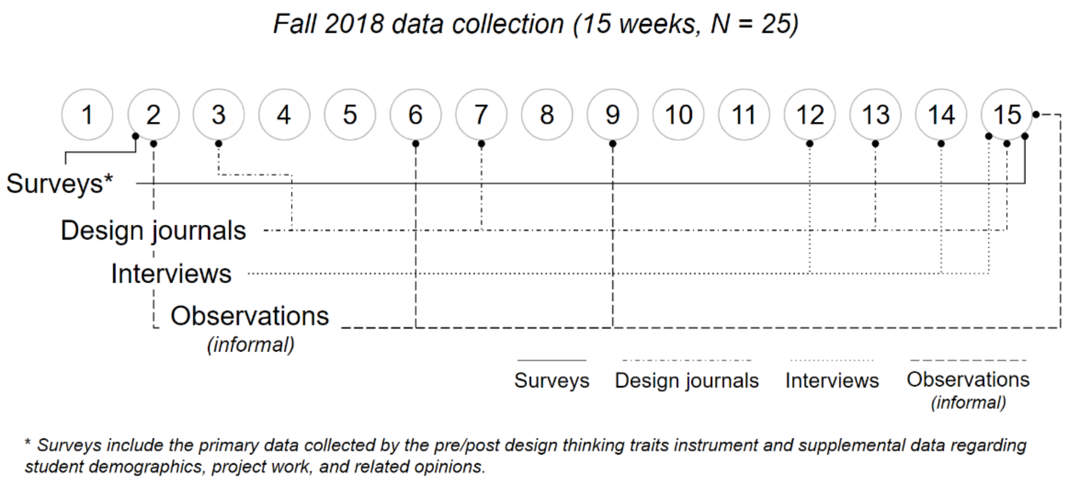

Figure 19. Fall 2018 data collection (15 weeks, N = 25)

Surveys were administered a total of three times—on Tuesday during week two and on Tuesday and Thursday during week 15. Design journal data was collected from all participant design journal entries submitted during weeks three, seven, 13, and 15. Five student interviews were conducted during weeks 12, 14, and 15. Informal observation and participation in class activities occurred four times during weeks two, six, nine, and 15, which generated field notes and images of student work. A data collection schedule for the study is in Appendix G.

Figure 20 shows the multiple methods used for this study within the context of the "cycle of expansive transition" (Engeström, 2014) and the 15-week design course duration. Care was taken to embed the data gathering instruments into regular course activity and to align data gathering with the cycle of expansive transition.

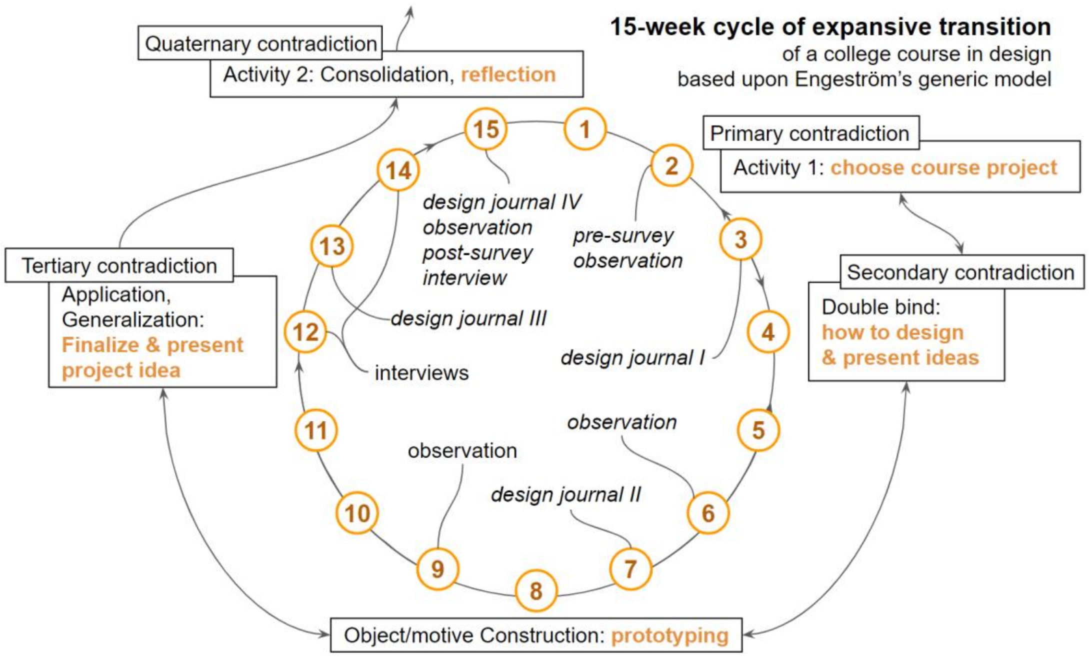

Figure 20. The cycle of expansive transition facilitated by a college course in creative design, plus research methods. Adapted from "Learning by Expanding (2nd ed.)." by Engeström, 2014, Cambridge: Cambridge University Press, p. 252.

Data collection was embedded in the design of the course and was aligned with activity theory's cycle of expansive transition. Design journals were part of students' regular coursework. The instructor informed me as appropriate days for observation became available. During these class meetings, students shared prototypes or final versions of their projects as part of the existing course design. Surveys and interviews occurred during regular class hours, and the instructor informed me as appropriate days and times to distribute surveys and request interviews became available. At agreed-upon times I visited the class to request participant interviews. Rewards (e.g., gift cards) were not offered to participants as to not influence their choices to grant interviews or to make them feel obligated to provide favorable accounts of their course experience. When students agreed to provide interviews, we left the classroom, and the interview was conducted in a private room in the same building the class was held. When the interview was complete, the student returned to the classroom.

Description of Instrumentation

There were primary and supplemental categories of data collection instruments. Primary data was collected with:

- survey form A (Appendix H)
- survey form B (Appendix I)
- design journal prompts (Appendix J)
- open-ended interview questions (Appendix K.)

Supplemental data was collected with classroom observations, surveys, and course documentation. A summary table of all data collection instruments is provided be in Table 24.

Table 24

Summary of Data Instruments

Data gathered	Instrument name and summary
Primary Data	
• Design thinking traits (n = 22, handouts)	Survey forms A, B: Design thinking traits (week 2, 9 items)
• Student reflections (n = 25, electronic)	Journal I – IV weeks 3, 7, 13, 15
• Student interviews (n = 5, face-to-face)	Semi-structured weeks 12 (2), 14 (2), 15 (1)
Supplemental Data	
• Demographic information (n = 22, handouts)	Survey form A: Student demographic survey (week 2, 6 items)
• Instructional preferences (n = 22, handouts)	Survey form A: Instructional preferences (week 2, 3 items)
• Design thinking knowledge and ability (n = 22, handouts)	Survey forms A, B: Design thinking self-assessment (week 2, 1 item)
• Idea and time count (n = 24, handouts)	Survey form B: Project idea generation (week 15, 3 items)
• Project name, audience, and tools (n = 24, handouts)	Survey form C: Project information (week 15, 3 items)
• Design thinking knowledge and ability (n = 24, handouts)	Survey form C: Design thinking self-assessment (week 15, 1 item)
• Helpfulness of design journals (n = 24, handouts)	Survey form C: Helpfulness of design journals (week 15, 1 item)
• Design definitions (n = 20, handouts)	Survey form C: Student design definitions (week 15, 1 item)

Primary data instruments. Primary data was collected with pre and post design thinking traits survey instruments, a series of four design journal prompts, and five participant interviews.

Design thinking traits survey. A survey to measure design thinking traits was used as a pre/post assessment instrument (Blizzard et al., 2015). The first instance of the survey was administered as a part of the survey form A (Appendix H), which also collected supplemental data. For reference, a stand-alone design thinking traits survey is provided in Appendix L.

Twenty-two participants completed both the pre and post-surveys. The response rate was 76%. Three of the 28 students enrolled in the course did not provide informed consent, and three of the participants were not present for either the pre or post versions of the survey. Twenty-two of the participants completed the pre-survey, and 24 of the students completed the post-survey.

The survey consisted of nine statement items representing design thinking traits, and respondents' agreement was indicated with a five-point Likert scale response format (Trochim & Donnelly, 2008). Scores of five indicated *strongly agree,* and a score of one indicated *strongly disagree*. The nine statement items were representative of five underlying factors the survey creators (Blizzard et al., 2015) identified as supportive of design thinking behaviors. To extend aspects of this survey to qualitative content analysis of the journal and interview texts collected in this study, the preexisting five underlying factors of design thinking that Blizzard et al. (2015) identified were elaborated with additional constructs found in the literature review and integrated into the coding scheme used for this study. The nine statement items used for the survey that Blizzard et al. (2015) mapped onto their five-factor design thinking structure are displayed in Table 25.

Table 25

Design Thinking Traits, Descriptions, and Statement Survey Items

Design thinking factors and traits	Statement items
Feedback Seekers They ask questions and look for input from others to make decisions and change directions.	• I seek input from those with a different perspective from me. • I seek feedback and suggestions for personal improvement.
Integrative Thinking They can analyze at a detailed and holistic level to develop novel solutions.	• I analyze projects broadly to find a solution that will have the greatest impact. • I identify relationships between topics from different courses.
Optimism They don't back down from challenging problems.	• I can personally contribute to a sustainable future. • Nothing I can do will make things better in other places on the planet (negative).
Experimentalism They ask questions and take new approaches to problem solving.	• When problem solving, I focus on the relationships between issues.
Collaboration They work with many different disciplines and often have experience in more than just one field.	• I hope to gain general knowledge across multiple fields. • I often learn from my classmates.

Note: From "Using Survey Questions to Identify and Learn More About Those Who Exhibit Design Thinking Traits." by J. Blizzard, L. Klotz, G. Potvin, Z. Hazari, J. Cribbs, and A. Godwin, 2015, Design Studies, 38, p. 103. Copyright 2015 by Elsevier. Reprinted with permission.

The development of these nine statements about design thinking began with a review of the design thinking literature as summarized in (Blizzard et al., 2012; Blizzard & Klotz, 2012) and was used to generate the 18 statement items displayed in Table 26.

Table 26

18 Potential Design Thinking Statements

All 18 potential design thinking questions
Helping others (respondents indicated the importance of statement)
I seek input from those with a different perspective from me
I think of myself as part of nature, not separate from it
I prefer to focus on details and leave the big picture to others
I prefer to focus on the big picture and leave the details to others
I identify relationships between topics from different courses
I analyze projects broadly to find a solution that will have the greatest impact
When problems solving, I focus on the relationship between issues
When problem solving, I optimize each part of a project to produce the best result
Solving societal problems (respondents indicated importance of statement)
Environmental problems make the future look hopeless
I can personally contribute to a sustainable future
Nothing I can do will make things better in other places on the planet
Inventing/designing things (respondents indicated importance of statement)
I seek feedback and suggestions for personal improvement
Working with people (respondents indicated importance of statement)
I hope to gain general knowledge across multiple fields
I often learn from my classmates

Note: From "Using Survey Questions to Identify and Learn More About Those Who Exhibit Design Thinking Traits." by J. Blizzard, L. Klotz, G. Potvin, Z. Hazari, J. Cribbs, and A. Godwin, 2015, Design Studies, 38, p. 100. Copyright 2015 by Elsevier. Reprinted with permission.

The initial drafts of the statements were refined based on feedback from "…educators with expertise in design thinking" (Blizzard et al., 2015, p. 95). The statements were aggregated, administered as a survey, and piloted across several iterations with two groups of students from two different 4-year institutions. Also, student focus groups were used to gather data surrounding the interpretation of the survey questions. The result from this set of procedures was either a redrafting or elimination of the individual statements to improve the clarity, face validity, and content validity.

The outcome of this process was a set of 18 statements, "..intended to identify design thinkers" (Blizzard et al., 2015, p. 94). The next step was to append these 18 statements to a pre-existing instrument, The Sustainability and Gender in Engineering (SaGE) survey. This hybrid of the design thinking traits statements and the pre-existing SaGE survey was administered to a random sample of 50 higher education institutions across the United States. Responses (N=6772) were received from all 50 institutions surveyed.

Exploratory factor analysis was applied to the survey response data and resulted in the reduction of the 18 initial design thinking statements to a total of nine design thinking statements. Statement items were found to positively or negatively correlate with other statement items in the set. Highly correlated statement items were assumed to be influenced by a common underlying factor and were collapsed. Statement items that showed a low correlation with the other items in the set were assumed to have unique underlying factors and were retained. This procedure yielded the nine design thinking traits survey items used in this study.

Blizzard et al. (2015) used statistical analysis was also used to identify themes relating to the initial 18 item statements and ultimately resulted in the identification of five underlying factors, which were used to organize the nine-item statements into five groups. Five methods were used (four statistical and one literature-based) to guide interpretation of the data and map this five-factor structure to the nine design thinking statements. When applied to the original 18 design thinking statements, a scree-test recommended the extraction of nine factors, while parallel analysis recommended the extraction of eight factors. A matrix showing the correlations between each pair of questions was generated, and a cluster analysis resulted in a recommendation to reduce the number of factors to less than either the scree-test or parallel analysis suggested.

Blizzard et al. (2015) calculated a Cronbach alpha value to measure the internal consistency of the statements and to decide if they all measured the same latent construct of design thinking. A single latent construct "...is a variable that cannot be directly observed, but is instead inferred from other variables that can be" (Blizzard et al., 2015, p. 104). Calculations yielded a Cronbach's variable of 0.76—just over the 0.7 value generally considered to indicate a set of statements measures a single latent construct (Peterson, 1994). This procedure helped to establish the reliability of the instrument.

Design thinking literature helped inform the decision to settle upon five underlying factors supporting the design thinking statements since "…design thinking is typically defined with fewer characteristics than the scree and parallel analysis tests were recommending" (Blizzard et al., 2015, p. 99). Moreover, this five-factor structure was selected after testing structures ranging from three to nine for statistical significance. The authors suggested the design thinking traits statements could be used in subsequent research to identify students who exhibit design thinking traits.

Design journals. A series of four design journal entries were integrated with a design studio pedagogy (Mathews, 2010) and were submitted by students during weeks three, seven, 13, and 15 of the course. Prompts were based on those developed in previous iterations of the course and were modified by the Fall 2018 instructor. The prompts were open-ended and intended to help students reflect on their project work. These assignments were not graded for content but only for completion. Word counts of 300 to 400 words were suggested but not strictly enforced. The journals were part of normal course work and were submitted to the course LMS. The design journal data consisted of entries from the 25 participants who provided informed consent. Of the 28 total students enrolled in the course, three did not provide informed consent, and their design journal data was not used in this study.

The first prompt, in week three, encouraged students to choose project topics that were personally meaningful to them and write about their ideas for potential projects. The second prompt, in week 13, asked students to write about their ideas for prototyping and the tools they might use to do so. It also encouraged them to write about any "difficulties, challenges, or frustrations" they were having, which was an attempt to gather data regarding the construct of contradictions, which is central to activity system analysis. The third prompt, in week 13, encouraged students to write about how their projects' target users were influencing the design process. The prompt for "difficulties, challenges, or frustrations" was reiterated with an additional request for students to write about successes in their project work. The fourth prompt, in week 15 and the last week of the course, encouraged students to reflect on their project work and write about feelings of confusion, challenges, or stress and how they related to project work. Students were also asked to reflect upon the "most valuable things" they learned and how their course experience might affect their use of technology in the future. The design journal prompts used for this study are in Appendix J.

A statement item was included in Survey Form C to gauge the significance participants ascribed to their journal entries. The item was, *My design journal entries helped me think and learn about design*. Participants were asked to indicate their level of agreement using an ordinal five-point Likert response scale. A score of one indicated *strongly disagree*, and a score of five indicated *strongly agree*. Survey Form C is in Appendix I.

Interviews.

Five interviews were conducted. The interviews were semi-structured and followed an interview protocol featuring open questions and probes. The form of the interviews was phenomenological in that their purpose was to obtain “detailed and in-depth descriptions of human experiences” (Roulston, 2010, p. 16). The interviews were not a normal part of the course, although they did take place within the normal course hours and supported student reflection on project work. Informed consent was provided by all five of the participants who were interviewed.

Two students were interviewed during week 12, two students were interviewed during week 14, and one student was interviewed during week 15. Interviews occurred in the same building classes were held in a separate, private meeting room provided by the University. Interview questions are in the list below, and the interview protocol is in Appendix K.

1. Would you talk a little about what your project is and how you got the idea for it?
2. Where there any challenges you encountered in your project work?
3. Were you able to resolve those challenges? How? Or, why not?
4. What tools did you use to make your project?
5. Did you feel like you had the freedom to do the kind of project you wanted to do?
6. Did anyone influence your project work?
7. What does “design” mean to you?

The length of the interviews ranged from 15 to 45 minutes. All but one of the interviews were 30 or more minutes in length, and the shortest interview lasted a little over 15 minutes. Brief notes were taken after each interview to record general impressions of the interview session. Usually that same day, the audio was exported, processed, and uploaded to an online transcription service. The resulting transcripts were compared to the original audio, and corrections were made as necessary. Interviews were transcribed verbatim. Once all interviews were completed and accurately transcribed, each interview was converted into separate MS Word documents and imported into NVivo software for further processing and analysis.

Supplemental data instruments. Supplemental data was collected via (a) informal classroom observations, (b) Survey Form A (c) Survey Forms B and C, and (d) course documentation. Supplemental data was used informally and were not formally analyzed.

Classroom observations. Informal observations were used to elaborate primary data sources anecdotally, and the observations were not formally analyzed. A camera phone was used to take some pictures of in-class prototyping activities (e.g., sketching) and prototypes (e.g., prototype presentations) during classroom observations. Images of in-class prototyping activity are in Appendix M, and images of participant prototypes are in Appendix N.

I visited and observed the classroom site seven times during the semester. Three of those visits were solely dedicated to informal observation and participation in class activities. Three of the classroom visits were to administer surveys and to request interview volunteers. The first visit to the classroom was during the second week of the course, just after the course’s drop/add window closed. The main purpose of this classroom visit was to introduce my research, to distribute informed consent forms, and to distribute surveys to students in the course. When these tasks were completed, I told the class I may return at some point in the semester to see what they were making, thanked the students and the instructor for their time, and excused myself from the classroom.

During week six, I visited and participated in student elevator pitches, which involved each student standing before the class, presenting a project idea, and a brief group feedback activity. During week nine, I visited and participated in prototype presentation day, which involved students displaying prototypes while others cycled the room to view and provide feedback on each prototype.

During weeks 12 and 14, I visited the classes to request interviews from the students. There was minimal time for observation, and yet it was possible to get a sense of the class because I was able to observe the instructor’s introduction, which included summaries of previous and upcoming activities.

During week 15, I visited the classrooms on Tuesday and Thursday. On Tuesday, I administered the post design thinking traits survey and made an unsuccessful attempt to gain another student interview. On Thursday, I observed and participated in the final project day, which involved students sitting at their tables and displaying their final projects to students and visitors. I administered a final survey and was able to get one last student interview.

Survey form A. Survey Form A was administered during the second week of the course. It included the first instance of the design thinking traits survey. The six-item student demographic survey was also administered and was combined with the nine-item design thinking traits pre-survey, a three-item survey of students' instructional preferences, and a single item survey of students' self-assessment of design thinking knowledge. A five-item creativity survey was also included for the course instructor but was not used for this study.

The demographic survey collected students' names, genders, ages, college levels, and majors. There were 28 students enrolled in the course. Three students did not provide informed consent, and three participants did provide informed consent but did not take the survey. Therefore, 22 participants completed Survey Form A, which was administered during week two of the course and is in Appendix H.

Survey Forms B and C. Survey Forms B and C were administered during the final two class meetings. Survey form B combined the second instance of the nine-item design thinking survey with three items that asked participants when they first got the ideas for their project topics, how many project topics they considered, and how long it took to settle upon a course project topic.

Survey form C was administered during the final class meeting and consisted of six items. These items gathered project information, including project name, project target audience, project tools used. An item was repeated from survey form A and asked students to self-assess design thinking knowledge and ability. The fifth item asked students to rate the helpfulness of their design journals. The final item was open-ended as asked students to provide a personal definition of design. All 25 participants completed these surveys, and any responses obtained from the three students who did not provide informed consent were discarded. Survey Forms B and C are in Appendix I, and their results are in Appendix O.

Course documentation. The syllabus was generated by the instructor and described the layout of the course, how grades were earned, and learning goals for students. The syllabus is in Appendix D. The main homework assignments were a watch/read and reflect assignment (Appendix P), a journey map assignment (Appendix Q), a creative design guideline assignment (Appendix R), and tool reports (Appendix S).

The watch/read and reflect assignment (week two) involved students watching or reading materials presented by David Kelley, co-founder of IDEO design company, and then posting brief reflections in the course LMS about what they read or watched. The journey map assignment (week four) asked students to interview target users for their project ideas and map out user information, needs, and product functions. The creative design guideline assignment (week four) asked students to (a) define the target audience, (b) explain the "magical experience" their product might create for users, and (c) generate alternatives to traditional design solutions. The tool report assignments (week 10) asked students to generate and share short demonstration videos of tools they were learning and using for their project work. Member checking was used to validate descriptions of the course instructor's education, research interests, course design, in-class demonstrations, and course goals for students.

Data Analysis

The unit of analysis for this study was the course as an activity system. Exploratory mixed methods were used within the analytical framework of activity theory. Pre and post survey results from an independent samples t-test assuming unequal variances were used to analyze the design thinking traits survey data. Thematic analysis, coding, and quantitative data analysis (i.e., quantizing and rank ordering code frequency) was used to analyze the journal and interview data.

Analysis and interpretation was linked to the overall system of activity. Engeström (2001) suggested activity systems as the prime unit of analysis was the first principle of activity theory.

Design thinking traits survey analysis. Microsoft Excel was used to run an independent samples t-test to compare the pre and post-test scores of the design thinking traits surveys (Blizzard et al., 2015), which were administered to the participants via paper handouts during weeks two and 15 of the course. The survey response rate was 79%, with 22 participants completing both surveys. Participants rated each of the nine statement items in the surveys using a five-point Likert scale. The resulting raw scores were input into a spreadsheet. Means and variances were calculated for each set of scores, and a t-statistic was calculated to compare the two sets of scores for a statistically significant difference. Any identifying information was deleted once the input data was triple checked for accuracy against the original handouts. After identifying information was redacted from the original handouts, they were placed in storage.

Developing a coding scheme. During previous versions (Fall 2015 through Spring 2017) of this course, I identified student journal assignments as valuable sources of data. This led to the first sketch of the coding scheme used in this study when procedures and techniques from grounded theory (Strauss & Corbin, 1990) were used to identify themes in student design journals inductively. An example of the initial coding work is in Appendix T. Eight categories were identified in design journal texts that also aligned with the analytical framework offered by activity theory. Some of these categories ended up as codes in the coding scheme used for this study, and these categories were as follows: exploring project options, tool exploration, challenges/contradictions/tensions, resolution of challenges/contradictions/tensions, evidence of design thinking methods, evidence of increased creative capacity, evidence of existing activity systems, and evidence of new activity systems. The design thinking and creative capacity codes were substantially elaborated for this study.

A combination of thematic analysis (Braun & Clarke, 2006), directed content analysis (Hsieh & Shannon, 2005; Morgan, 1993), activity theory (Engeström, 2014; Jonassen, 2002), and an extensive literature review was used to build a coding scheme for coding and analyzing design journal and interview data. Thematic analysis (Braun & Clarke, 2006) provided procedural guidelines for developing the coding scheme. Six phases of thematic analysis were described by Braun and Clarke (2006) and are listed below.

1. Familiarizing yourself with the data;
2. Generating initial codes;
3. Searching for themes;
4. Reviewing themes;
5. Defining and naming themes;
6. Producing the report. (p. 87)

The development of the coding scheme continued in Fall 2018 while waiting on the data used for this study to accumulate. More themes were generated by reading the data and creating a set of *inductive buckets* and *deductive buckets* (Galman, 2016). Inductive buckets were created by identifying specific examples and details in the data and relating them to codes. Deductive buckets were created a priori with constructs identified by the literature review of activity theory, creativity, and design.

Inductive buckets. The inductive analysis identified themes in the data that were tentatively added to the coding scheme. Table 27 shows some examples of this process.

Table 27

Fall 2018 Inductive Analysis

Codes	Data – written text - quotes
exploring project options (expr)	• "I believe I have decided to go ahead and pursue the mobile app (which can open up online) which helps science majors study their notes more effectively." • "I have definitely settled on the mobile app with the accompanying website."
tool exploration (extl)	• "I do not yet have a plan for building it but I have perused a couple of app building sites." • "I'm not sure I want to use Sumopaint or the applications I have seen so far." • Marvel App: "I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one." • "I've moved from PowerPoint to Marvel App and a website and app to just an app. I've narrowed my scope and gone into depth on those things I've decided to focus on." • "Marvel App was able to show me what my project would look like on a phone instead of myself trying to configure that part on my own"
Confusion (xx)	• "The technology for all this however, I have no idea where to even begin. I only know how to make it very appealing to audiences." • "I'm struggling with Wordpress because the tutorials aren't helping for what I want. There isn't a real reason to have a blog or at least I haven't found a reason yet." • "Once again, struggling with the tools, I can't figure Lynda out. I need to ask soon what Lynda would be good for because everything I have seen about apps have been about developing them but I am only designing one? Kinda confused on that aspect."
Reaching beyond the learning context (bynd)	• "I went home this past weekend and began teaching my sibling how to create a blog so that she could put it on her college applications. I have no technology background and yet I was able to teach someone something. I consider that pretty cool." • "I feel much more comfortable using graphic designing programs and what now and in the future because in the process of building my app I have become more adventurous."

Deductive buckets. A review of the creativity, design, and activity theory literature for this study was used to generate most codes for the coding scheme. Table 28 shows the initial operationalizing of constructs so that they could be implemented as codes when reading data.

Table 28

Fall 2018 Initial Code Development–Deductive Analysis

Label	Description
Subjects/participants/characteristics	Who are they? What are their demographics? What are their subjectivities/attitudes?
Instruments (tools, technical and conceptual)	Within the activity, what tools are they using? Both technical and conceptual.
Objectives/goals	Within the activity, what are the subjects' objectives/goals? What are they making? Why are they making it?
Rules	Within the activity, what are the rules and how are they created?
Community	Within the activity, what is the community? How do subjects' access community both in and out of the classroom?
Divisional of labor/hierarchy of power	Within in the activity, how is the work distributed? How is autonomy distributed? How much "say so" do participants have in how the objective is achieved?
Tension/contradiction	Within the activity, are there tensions, contradictions, challenges? How do they emerge? Why? Are they resolved? If so, how?
Resolving challenges	Within the activity, how do the subjects cope with challenges? Was the challenge resolved? Did resolution lead to learning or expansion of the preexisting activity systems?
Design thinking	Attitudes and behaviors associated with design thinking. Is there evidence of human-centered design? Is there evidence of problem finding? Is there evidence of creating many options before settling upon solutions? Use of design thinking methods around target audience research? Trial and error procedures? Are there efforts at collaboration with peers or others outside of course?
Optimism	Are participants in the activity system optimistic about their project work?
Self-efficacy	Do participants in the activity system believe in their ability to use ideas from design thinking? Do participants believe in their ability to use technology?
Creative confidence/agency	Do participants in the activity system have confidence in their ability to be creative with their project work?

Description of the coding scheme. Thirty-eight codes comprised the coding scheme used for this study. The codebook, located in Appendix A, describes all codes and their implementation rules. The constructs (i.e., codes) were input into NVivo 12 qualitative and mixed-methods data analysis software as a set of *nodes* that were used for the coding of the journal and interview text data. Nodes and hierarchical node structures are NVivo's proprietary terms for user-defined criteria such as code definitions and coding schemes. Individual nodes (i.e., codes) and node structures (i.e., coding schemes) were used to identify (e.g., highlight, tag, markup) segments of text and build a database of evidence for each node. Direct content analysis (Hsieh & Shannon, 2005) was used to guide the coding procedure. This involved using the previously identified constructs in the literature review to identify and code segments of text, although some codes were generated inductively. After 1173 segments of texts from the journals and interviews were assigned to various nodes (i.e., codes), the software features were used to expedite multiple ways of modeling (i.e., representing) and analyzing the data.

Figure 21 shows the coding scheme broadly organized by the categories of activity theory, creative design ability, and project management. The category of project management was added inductively during analysis because the data suggested this was a key part of students' experience in the course and because project management did not necessarily seem to fit within the existing categories. The amount of references assigned to each code (i.e., construct) is indicated by the number in parentheses. An asterisk beside a number indicates the associated code was a "parent" code that was populated by its "children" codes, which are indicated by indentation beneath the parent code. Numbers with asterisks are the sum of both parent and child codes. During the analysis of the journal and interview data sets, the numbers for the parent codes were not aggregated from their children codes to avoid double counting the references.

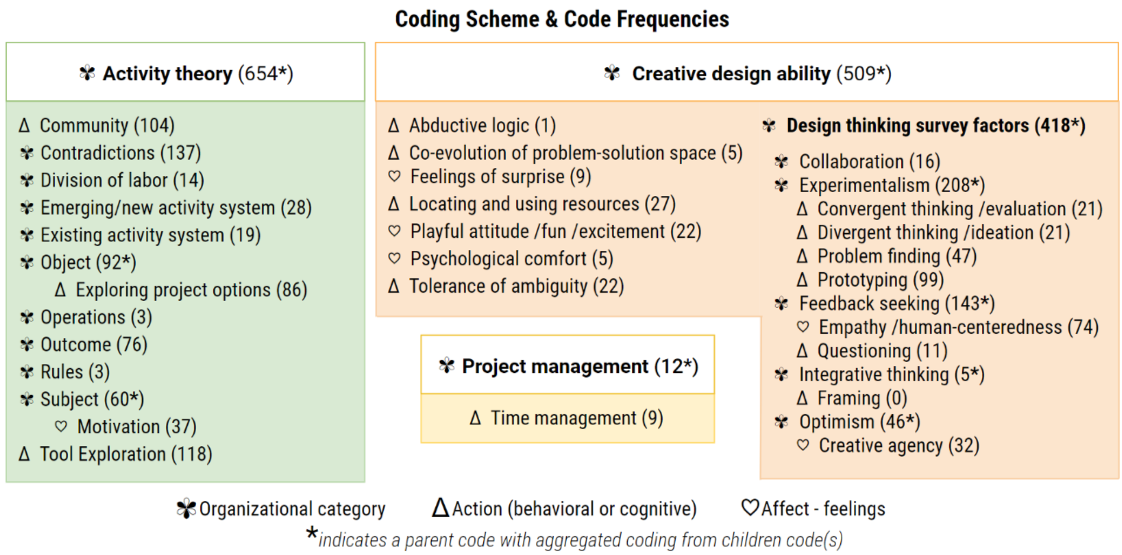

Figure 21. Coding scheme and code frequencies

In addition to counting how many times codes were referenced in the data, statistics were calculated to show many students referenced each code. This was done to strengthen the interpretation of the frequency counts and to check if the most frequently coded codes were also referenced by most participants. Otherwise, a minority of participants might skew the distribution of references in the group to a given code, which could have been misleading when interpreting code frequencies. For these calculations, five parent codes were omitted to avoid double counting of codes. Code frequencies and their spread across participants added to the trustworthiness of the interpretation of data.

For example, within the journal data set, the community code ranked seventh and spread across 72% of participants. However, community ranked first in the interview data, with 100% of participants represented. Furthermore, the median number of coded references per participant was two in the journals but 14 in the interviews—twice the amount of any other code in the interview data set. This technique added depth to the analysis of community as represented by the data and suggested that the community was a prominent factor in students' creative design process. Table 29 provides an example of the statistical comparison involved in this part of the data analysis.

Table 29

Comparison of Reference Counts and Students Referencing Between Journal and Interview Data

	Total references		Students who referenced the code		Median of references	
Name of code	Journals	Interviews	Journals	Interviews	Journals	Interviews
Tool exploration	81	35	70%	100%	3	7
Prototyping	73	26	70%	100%	3	4
Exploring project options	63	23	73%	80%	2	5
Empathy - human-centeredness	52	22	76%	80%	2	3
Community	**42**	**62**	**72%**	**100%**	**2**	**14**

Total references to each code, percentage of students who reference each code, the range of references for each code, and the median of references for each code were calculated separately for both the journal and interview data sets. Code frequencies within each of the four journal entries were calculated. Codes were then rank-ordered according to their overall frequency count across the journals. Also, the difference in frequency count from the first to the last journal entry was calculated for each code. A table is used to display the full set of this data in Appendix U.

Application of the coding scheme. Qualitative content analysis was used to apply the coding scheme to the textual data from participant journals and interviews. Morgan (1993) described counting codes as a part of qualitative content analysis and noted the practice was also a controversial way of analyzing text. The key characteristic of either quantitative or qualitative approaches to content analysis was, "The researcher uses a consistent set of codes to designate data segments that contain similar material" (p. 114). Within the qualitative content analysis, (a) how the codes were generated and (b) how the codes were used were described by a continuum with quantitative approaches on one end and qualitative approaches on the other.

There were quantitative and qualitative approaches to generating codes. Whereas quantitative procedures for code generation relied on search algorithms to automatically generate codes, qualitative approaches use a varying combination of inductive and deductive analysis to generate codes.

There were quantitative and qualitative approaches to the use of code counting. A quantitative approach concluded with a summary of the code counts and presentation of the numerical findings. A qualitative approach extended the procedure to interpret the patterns that resulted from the code counts. That is, "counts can be seen as both the end of a descriptive process and the beginning of an interpretive process" (Morgan, 1993, p. 116). It was observed how qualitative research often used quantification implicitly (e.g., most, nearly all) and asked, "If one is engaging in implicit counting, then why not do so explicitly?…[and] give the reader a tangible basis for assessing what the analyst claims are the important patterns in the data" (Morgan, 1993, pp. 117-118).

Counting codes as part of qualitative content analysis fits with the mixed-method research design used for this study and its efforts to consider design creativity from a systems perspective. Those interested in a more in-depth discussion of qualitative content analysis are recommended to refer to Crabtree and Miller (1992), Tesch (1990), and Berelson (1952). This study used qualitative content analysis to (1) count the frequency of codes in the textual data to identify the most active parts of participants' creative design process and to (2) interpret textual data that was emphasized by the code counting procedure.

Individual participants generated two grouped data sets. One was comprised of four subsets of sequential journal entries (n = 25) and the other of five individual interviews (n = 5). All data was coded, and text segments were assigned to one or more of the 38 codes in the coding scheme. Counts of the text references to each code generated frequency distributions for each code, which were rank-ordered for the total data set, the journal data set, and the interview data set. The rank ordering of codes was also done within four subsets of journal entries as defined by the week of entry. Similarly, the rank ordering of codes was done within each interview. To extend the reach of this technique, codes that intersected with top-ranking codes were also rank-ordered. This procedure was used to help identify what data was most descriptive of the activity system, which was the prime unit of analysis. Finally, the differences in frequency counts from the first to the last set of journal entries were calculated for each code and rank-ordered to help determine the prominence of each code in the activity system.

Codes were classified as either (a) organizational categories, (b) actions, or (c) affect/feelings. This was done to aid in the interpretation of data and not intended to suggest these classifications were mutually exclusive. The various codes intersected with each other a great deal. Organizational categories were either components of the analytical framework of activity theory (Engeström, 2014), design thinking factors specified in the design thinking traits survey (Blizzard et al., 2015), or container categories for them. The project management category was an exception. It was generated inductively and added to the coding scheme during analysis. Organizational categories were used as analytical hubs to investigate coded data and other codes that intersected with them.

Codes classified as organizational categories were often used to view their intersecting codes in order to identify text for analysis. For example, in the pooled data sets of journals and interviews, *contradictions* was the most referenced code and had 137 text references. A matrix query was performed within this code and revealed the most frequently intersecting codes were tool exploration, prototyping, and community. This technique was used to orient analysis (i.e., a close reading of the text) and draw inferences based on the intersections of these codes and the texts that were referenced by them. Furthermore, contradictions as the “sources of change and development” (Engeström, 2001, p. 136) were described as a principle of activity system analysis.

Action code classifications were used to identify behaviors (e.g., exploring project options, tool exploration, prototyping) and cognitive abilities (e.g., problem finding, tolerance of ambiguity, divergent thinking.) The community code was classified as an action code because the data described the community more in terms of doing and reflecting than as a static description. The action classification also reflects the three-level hierarchy proposed by activity theory, where goal-oriented actions (e.g., prototyping) were embedded within the overall activity (i.e., project work) and were linked with operations, which are conditional to a given action and often carried out automatically as habits, assumptions, or unconsciously performed routines. For this study, the methods used were not designed to detect unconsciously performed routines, and therefore the operations classification was not well populated. For this analysis, action code classifications were informed by the combination of activity theory and the reviewed literature on creativity and design.

Affect/feelings code classifications were used to identify emotional states students expressed in relation to their project work. The code for psychological safety (Amabile et al., 2005; Baer & Frese, 2003; Edmondson, 1999), was inductively identified. The references to and inferences from it were instrumental in the decision to designate a code classification for affect. A code classification was created that reflected affective states as conditional to actions and components of the activity system. Similarly to how operations are conditional to actions for activity system analysis, affective states were conditional to actions (e.g., an expression of creative agency might be conditional to successful prototyping actions) and the structural components of the activity system such as community. The affect/feelings code classification was used to suggest which components of the activity system shaped changes in affective states.

The coding scheme was also organized by parent-child relationships. For instance, the code for *motivation* was a child of the *subject* code because motivation was an important attribute of each participant. The most extensive use of parent-child relationships was with codes that elaborated upon the five design thinking factors identified in the review of the literature Blizzard et al. (2015) conducted to generate their survey, which was used as a pre-test post-test measure in this study. Eight codes (e.g., prototyping, empathy /human-centeredness, creative agency) were generated to extend the analytical reach of the design thinking factors identified by Blizzard et al. (2015). References to parent codes, or themes, were populated by the sum of other constructs that related to them. For example, the design thinking factor of *experimentalism* was a parent code for the constructs (a) *questioning*, (b) *problem finding*, (c) *divergent thinking – ideation*, (d) *convergent thinking – evaluation*, and (e) *prototyping*. During the analysis of the journal and interview data, reference counts of child codes were not aggregated to their parent codes to avoid double counting.

Also, a chronological series based on the dates of design journal submissions was used to organize the representation and analysis of the codes. Within each time period, the references to codes were rank-ordered. The rankings from one time period to the next were compared to highlight changes in the code rankings across time and to suggest dynamic relationships between the codes (i.e., themes, constructs) over time. Codes that most often intersected with each time period's top-ranking codes were used to identify text for subsequent analysis. Spreading analysis across multiple periods of time and then using intersecting codes to identify relevant data made it possible to get a dynamic sense of how the themes unfolded over time, and why. This analytical technique was in keeping with activity theory's emphasis on historical or chronological analysis—historicity was described by Engeström (2001) as a principle of activity theory.

Using software to facilitate coding and analysis. The following example will show how different cognitive actions within a period were linked to a component of an activity system and explain how this was accomplished using NVivo software. In Figure 22, the query process began by limiting the source data to design journal 1, as indicated by the checked box.

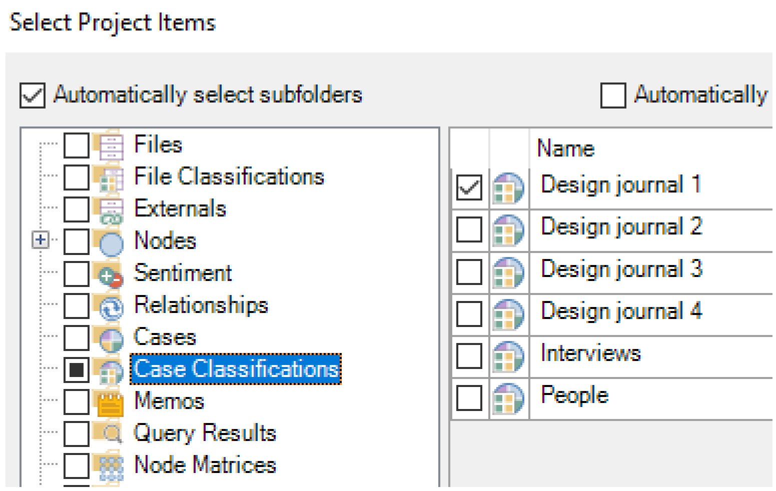

Figure 22. NVivo: Focusing on a segment of time

This constrained query results to the set of design journal one entries only. This was possible because, prior to importing the text data into NVivo, all student journal entries were combined into a single Microsoft Word document. Each participant and their respective journal entries were organized under Microsoft Word heading styles, and the document was saved, and the Microsoft Word program was closed. No further editing would be necessary in Microsoft Word, and the document would be imported into NVivo.

When importing the document into NVivo, the specified headings (e.g., "Heading 1" for participant, "Heading 2" for each journal entry) applied in Microsoft Word were used to differentiate individual participants, individual interviews, the journal data set, the interview data set, and each set of journal entries (e.g., Design journal I, Design Journal II…) so that NVivo would be able to recognize and import them as cases. Using NVivo's case features, participants and their journal entries were assigned as cases. Using NVivo's case classification features, participants and their journal entries were assigned various attributes. Participant case classification attributes were collected with surveys, such as demographic data and project information. Journal entry case classification attributes were assigned for each journal's date of entry and week of the course. Using case and case classifications along with the previously set up coding scheme (i.e., node structure), NVivo's matrix coding query feature was used to cross-reference nodes, cases, case classifications, and attributes. A similar procedure was used with the interview data.

This technique enabled a matrix query using the coding scheme (i.e., nodes) in combination with each set of journals and well as the entire data set, including either grouped or individual interviews. Therefore, comparisons of code frequencies between these various sets of data were possible.

Matrix queries involved comparing the coding scheme (i.e., node structure) with different aspects of the imported text, as was made possible by NVivo's case and case classification features. For example, it was possible to focus exclusively on data from journal 1, week 3 and thus constrain analysis to the beginning of students' design processes. The data set was limited to the first set of design journal entries as was shown in Figure 22. Within this selection, the data set could be further limited to references regarding the activity system's object, which is labeled as *Objective* and elaborated as *Exploring project options* as displayed with Figure 23. Exploring project options was a child code of the objective (i.e., object) code.

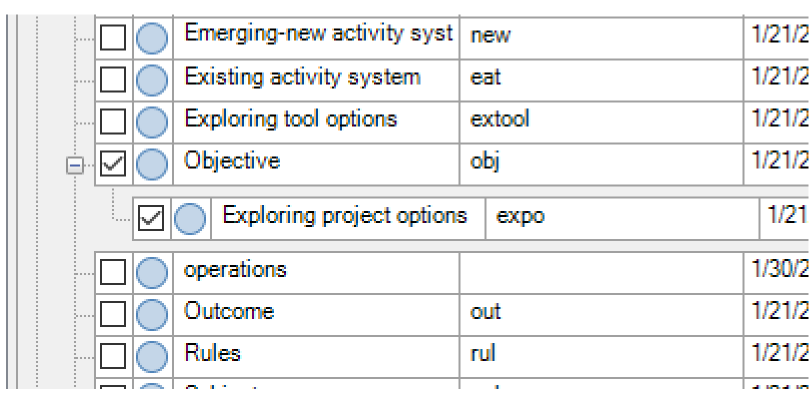

Figure 23. NVivo: selecting a "node" to query

In summary, at this point in the analytical procedure, the journal data set was constrained to (a) the first part of the course and (b) student reflections about the object of the system—final projects. Figure 24 shows the matrix coding query used for this example.

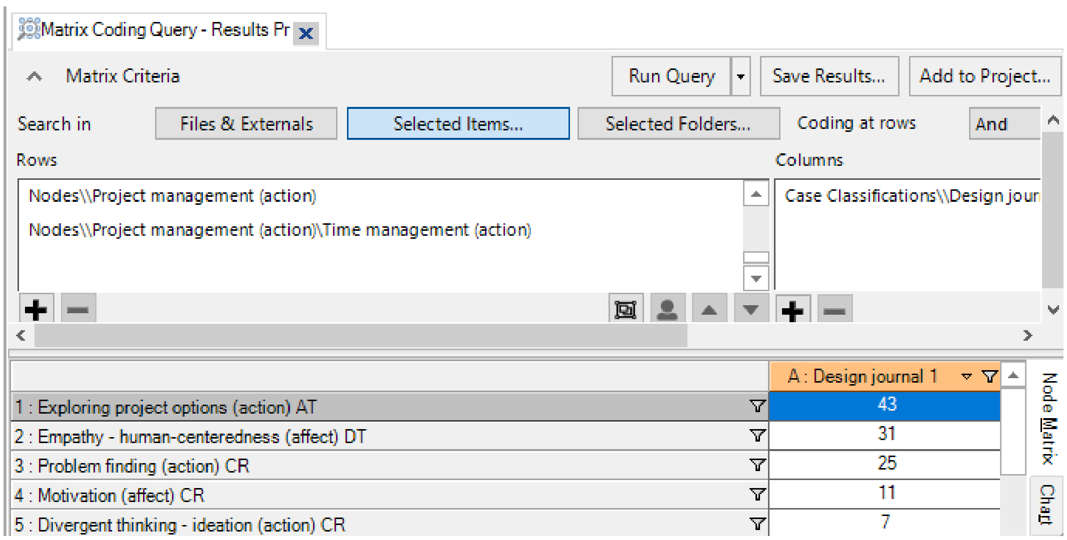

Figure 24. NVivo case and case classifications to select data

Matrix queries could be run in a myriad of ways, from a global count of coded references across the entire data set to a constraint involving only outcomes mentioned in the last journal and the intersecting codes, to a time series of code (i.e., nodes) rankings based upon the journal week of entry.

In Figure 25, a segment of text from journal one week three is displayed. The entire segment was coded as “Exploring project options.” During the early part of the course, this student was considering different topics for a project.

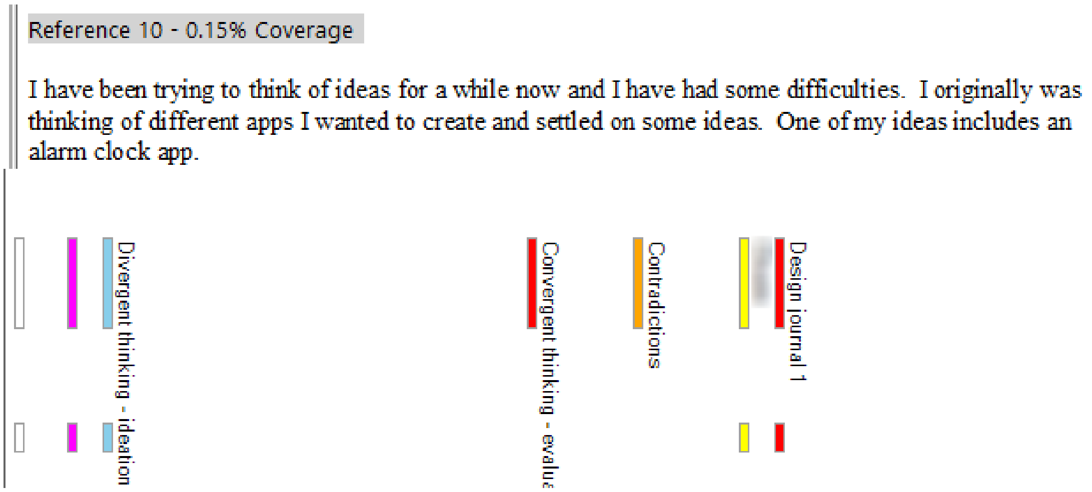

Figure 25. NVivo: intersecting, overlapping nodes

Codes (i.e., nodes) and cases (i.e., participants and journal entries) that overlapped with the segment of text were displayed perpendicular to the segment of text and were color-coded. They were divergent thinking – ideation, convergent thinking – evaluation, contradictions, a student identifier, and design journal 1. Because this student mentioned difficulties generating ideas, the contradictions code was implemented in tandem with the divergent thinking code. Because the student may have settled on some ideas, the convergent thinking code was also applied. This small example showed how a segment of text was tagged according to multiple factors such as time, participant ID, and constructs identified in the literature review.

There was no shortcut for accomplishing the initial coding. The literature review and manual coding processes were labor expensive but resulted in a coding scheme that can be refined and reused with new data sets. The codebook generated and used for this study is in Appendix A.

Display Procedures

All tables and charts involving quantitative data were generated with Microsoft Excel Office 365 version 1907. All matrix query results generated by NVivo 12 Plus were exported as spreadsheets and imported into Excel, at which point tables and charts were generated and finally exported into Microsoft Word. Descriptive statistics and their related tables were generated with Microsoft Excel. All conceptual graphics were generated with either Google Sheets or Affinity Designer 1.7.1.404 and imported into Microsoft Word as images.

The codes (i.e., constructs, themes, nodes) and the frequency with which they appear in the data are represented with tables and figures. Theoretical ideas from the literature, findings, and interpretations of the data are represented with figures. Tables were used to represent characteristics of project work regarding project types, project topics, and tools used for project work as collected by Survey Forms B and C. Statistical results from the design thinking surveys were displayed with tables generated in Excel, and a figure generated with Google Slides was used to represent demographic data. Screenshots were used to support the explanation of data preparation and analysis within the NVivo 12 Plus QDA software.

Limitations of the Study

Although the design thinking traits survey statement items (Blizzard et al., 2015) were well developed as part of a quantitative assessment instrument, its results for this study were not generalizable to larger populations. The sample size was small (n=22), there is no randomly assigned control group, and comparisons of treatment effects are not possible. Moreover, as with most psychological inventories (Huck, 2008), the response scale is ordinal and lacks equal intervals of measurement; this limitation would apply to the instrument results in any case. The course design was not rigidly specified to make reliable replication possible as an intervention or treatment conducive to statistical testing. Moreover, the variables of instructor knowledge and attitudes would make replication of the intervention even more challenging.

The journal prompts were probably too specific. The prompts asked participants to talk about aspects of their design process, such as generating project ideas, target audiences, prototyping, and software use. If the prompts had been more open-ended, the journal data would not have been skewed in the direction of the prompt details, and the frequency counts of the codes would have provided a more authentic representation of participants' project work experience. This limitation was a result of tension between pedagogical and research goals. The working pedagogical objective emphasized salient aspects of the creative design process and encouraged student reflection, whereas the research methodology might have been strengthened had the journal prompts been less guiding and more open-ended.

Given that the text data was quantized, it was a limitation (or missed opportunity) that no interrater reliability was calculated. This was understandable since I was the sole researcher, but the coding results might have been strengthened had there been more than one coder, and a method for quantifying interrater reliability was used.

Another limitation was that the interviewees were all enthusiastic volunteers. This is good for gathering perspectives of those engaged with the course but missed data from those students who were not as engaged in coursework. Hearing from those students who did not enjoy or were not otherwise engaged with the course would have provided helpful insight. Another limitation was the lack of member checks. Although a member check was done with the course instructor, it was not done with the student participants. The data were not fully collected and read until the course was over, and students had left the system.

Another limitation was the lack of a micro level of analysis of the creative design process, albeit the goal of this study was to look at the whole (macro) process over the course of the semester, and fine grain of analysis was not expected. Nonetheless, there are aspects of creative design ability that might only be observed by methods absent from this study, such as protocol analysis involving audiovisual data collection methods. The lack of micro data was apparent due to the lack of text references to the *operations* code.

Implicit in qualitative methods is researcher bias. In these cases, researchers *are* instruments of measurement. As scrupulous and attendant to the recognition of bias as a person might be, the subjectivity of perception cannot be escaped. However, researchers' unique insight into the data can be a valuable advantage of qualitative methods. Even in guarding against validity errors via techniques such as triangulation, member checks, and *thick description* (Geertz, 1973) "…the researcher ultimately comes to offer a personal view" (Stake, 1995, p. 42).

Finally, there are no natural stopping rules for the creative design process, which suggests a limitation of time. Perhaps one semester was not enough time to understand how design thinking developed for the participants. Perhaps the length of the interviews and lack of a series of them limited the possible findings. For developmental learning cycles, there is the possibility that participants will consolidate their knowledge after data collection has concluded.

Ethical Considerations

For this study, there was no conflict of interest between the research goals and research methods. Full disclosure and explanation of the research contributions requested was made to all participants.

Given this study was conducted with undergraduate students, both the course instructor and I emphasized to them all that choosing not to participate would make no difference to their grades and that the course instructor would not be made aware of which students chose to participate and which students did not choose to participate.

Respect and consideration for participants' time, privacy, well-being, and lawful rights guided my conduct with participants in this study. Respect for participants was shown in practical ways, and data collection was accomplished as unobtrusively as possible. Privacy was honored for participants. All collected data is confidential. All personal identifiers were removed from the data as soon as it was practical. Interviews and meetings were scheduled at the convenience of the participants.

Researcher Subjectivities and Assumptions

Personal epistemology. I believe most people learn by understanding the context of their actions and the interplay between the two. And, learning becomes deeper and more meaningful when people repeatedly connect to their object of interest through multiple modes of thought and action. I think people are "lifelong learners" when they have the qualities of curiosity and intellectual humility (Rosling, 2018) and that these qualities are prerequisites for self-directed learning. I believe people are social animals with advanced capabilities for tool use and abstract thought. Therefore, ideas from social constructivism (Vygotsky, 1978) and constructionism (Crotty, 1998; Papert & Harel, 1991) resonate with me the most. But I also believe learning happens across a continuum of designs ranging from direct instruction on one end and constructionism on the other—including no design at all. I think active and self-directed learning is optimal learning, and I also think well designed and implemented direct instruction can work better than poorly designed and implemented constructivist learning environments.

Relationship to the study site. I worked as an instructor in this class for two years and taught six sections across four semesters. I also worked as the assistant for an online version of this class. When I began work in Fall 2015, the course was named, and project-based. From this starting point, I designed the course based on my knowledge and experience. I began my collaboration with the instructor for the current course site of this study during the Fall of 2015. We collaborated on the design of the course for this study and have also co-presented multiple times about the course and surrounding research. I have been deeply involved in this course for the past several years.

The primary site for this study was the same course and had a similar design to that of the preliminary course designs. The main difference between the preliminary course designs (Fall 2015 – Spring 2017) and the primary course design (Fall 2018) was that the course was led by a different instructor. Although the Fall 2018 course design was based upon the previous course design, the instructor had free reign in making changes to the course design and methods, just as I had been given when first teaching the course in Fall 2015. We held shared epistemological beliefs regarding creativity, design thinking, and learning. Our collaboration resulted in several presentations over the years at different conferences (McCalla & Li, 2016b, 2016a, 2017a, 2017e, 2017d, 2017b, 2017c, 2018b, 2018a), and the collaboration continued into Fall 2018 as I collected data for this study.

Due to my previous experience and research relationship with the instructor, I was able to have confidence that the course design would work with my research methods. That is, the course had a strong project-based learning orientation, learners were given a high degree of autonomy (and with this were required to formulate project ideas without being told what to do), and learners were given support in their efforts to be creative in their design work. It is these qualities of the course that supplied my students (in my estimation) with the conditions for intrinsic motivation to complete the course work and afforded a range of authentic, non-trivial challenges to students. I wanted to study students who were engaged with creative design and would have been disappointed with a group of students who were disengaged, although that would not have posed a problem in carrying out the research. The way this course was designed, the course could function as a formative intervention that engaged the students' agency.

CHAPTER 4

FINDINGS

These findings are based upon the primary data, which consisted of design thinking traits survey results, participant design journals, and participant interviews. The design thinking traits survey (Blizzard et al., 2015) pre-post t-test results showed a statistically significant increase in design thinking traits for the group of student participants in this course. The three main findings were (1) how high levels of learner autonomy supported participants' motivation, (2) how extensively the course community supported the development of participants' design abilities, and (3) how these factors led to new attitudes toward creativity, i.e., participants' newly felt *creative agency* (Karwowski & Beghetto, 2018; Royalty et al., 2014).

Journal data showed participants' discussed tool exploration, prototyping, project identification, and community the most. Empathy/human-centeredness and creative agency were the two most prominent affective states reported by participants in their journals. Participant interview data showed community, tool exploration, feedback seeking, and prototyping were the most frequently discussed actions. Empathy/human-centeredness, motivation, and playful attitudes were the three most frequently discussed by the interview participants. Figure 26 summarizes these high-level findings.

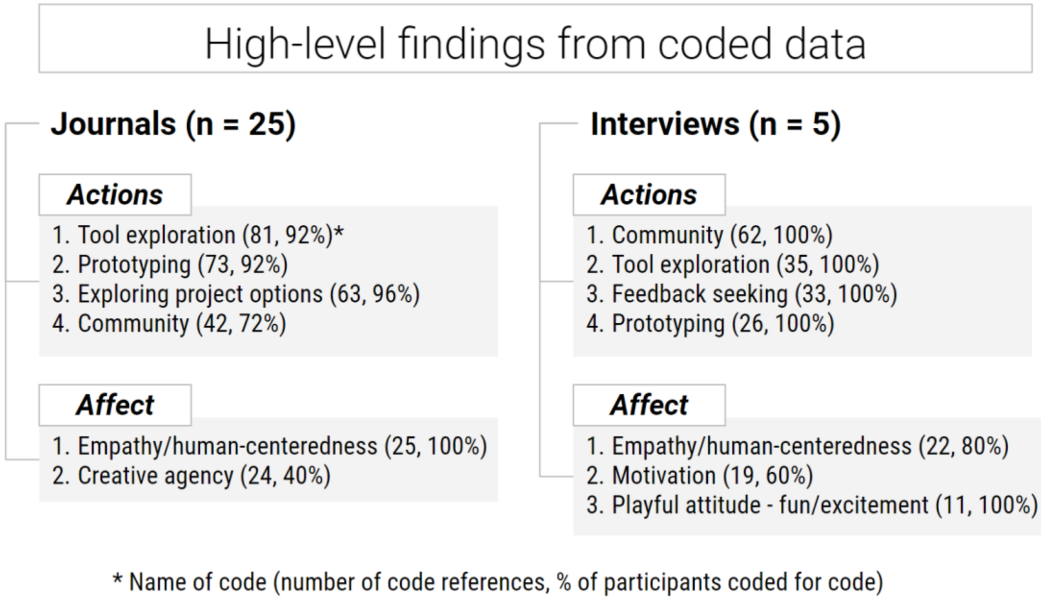

Figure 26. High-level findings from coded data

Overall, the data showed that learning to use design software for prototyping within the context of a supportive community was characterized by increases in the adoption of human-centered design methods, playful attitudes toward project work, sustained motivation throughout project work, and increased feelings of creative agency.

Design Journal Data

Word counts and participant opinion. The summed total word count of participant journal texts was 24,511. Word counts of each participant's complete set averaged 980 and ranged from 474 to 1606. The average word count for individual journal entries was 245. Figure 27 shows the average journal word counts for each set of entries across the length of the course.

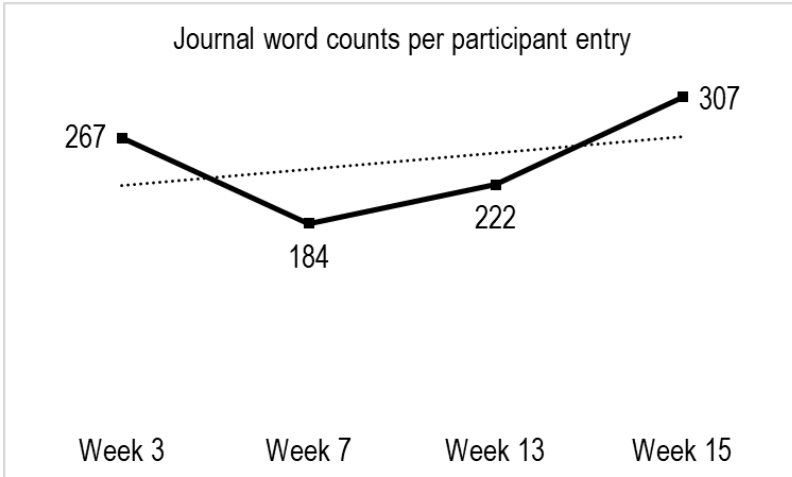

Figure 27. Average journal word counts per student per entry

Participants indicated their journal entries were valuable to their creative design process. Participants were surveyed (n = 24) on the last day of class and asked to indicate their agreement with the statement, "My design journal entries helped me think and learn about design." Two participants' responses were neutral, and the remaining participants indicated their agreement. Table 30 displays descriptive statistics for this survey item.

Table 30

Student Opinion on the Helpfulness of Design Journals

"My design journal entries helped me think and learn about design." (Likert response scale 1-5)	
Mean	4.33
Median	4
Mode	4
Standard Deviation	0.64
Range	2
Minimum	3
Maximum	5
Count	24

Overall journal code rankings. Codes that referenced segments of journal text were rank-ordered using a count of the total number of references to each code. Also, percentages were calculated to show the percentage of participants who were referenced by the code. Five of the 38 codes were omitted from the rankings because they were parent codes, and their associated child codes represented them in the rankings. Five additional codes were absent from the rankings because they were not assigned when analyzing the journal data. Table 31 shows the codes referenced by at least 40% of the participants. All journal code rankings are displayed as a table in Appendix V.

Table 31

Journal Code Rankings

Code	Frequency	Spread[a]	Category
Contradictions	112	100%	parent
Tool exploration	81	92%	action
Prototyping	73	92%	action
Exploring project options	63	96%	action
Outcome	59	96%	organizational
Empathy/human-centeredness	52	100%	affect
Community	42	72%	action
Feedback seeking	36	72%	parent
Problem finding	33	80%	action
Creative agency	24	40%	affect
Motivation	18	44%	affect
Locating and using resources	17	48%	action
Convergent thinking/evaluation	16	40%	action

[a] Percentage of participants who were coded for each code

Codes that intersected with the code for contradictions showed the qualities of the challenges participants faced in their project work, and many of the challenges involved learning to use software design tools and prototyping design ideas. The codes that most frequently intersected with the contradictions code were tool exploration (33) and prototyping (22.) As participants began project work, there were frequent mentions of different options that were considered for final project topics (exploring project options: frequency: 63, coverage: 96%.) This involved a human-centered approach (empathy/human-centeredness: frequency: 52, coverage: 100%) in choosing project ideas by considering the problems other people experienced and different ways those problems might be addressed by their project ideas, which showed evidence of problem finding behavior (problem finding: frequency: 33, coverage: 80%.). While these code rankings helped to show different aspects of participant development, a time series showed the codes sequentially across participants' creative design process.

Code rankings were segmented according to the different weeks of the four journal entries and reflected sequential dynamics of participants' creative design process, and the changes in code frequencies across the time series suggested some dynamics of a general developmental process. Table 32 shows the most prominent code frequencies per journal and the net change of each code from the first to the last journal entry. Code frequencies per journal and their net changes are displayed for all codes in Appendix W.

Table 32

Code Frequency and Rankings Across Journal Series

Code	Journals				
	I	II	III	IV	Change[a]
Contradictions	2	**28**	**35**	**47**	+45
Tool exploration	0	**21**	**35**	**25**	+25
Prototyping	1	**29**	**32**	11	+10
Exploring project options	**43**	8	3	9	-34
Outcome	1	0	1	**57**	+56
Empathy/human-centeredness	**31**	6	10	5	-26
Community	5	8	12	17	+12
Feedback seeking	0	3	20	13	+13
Problem finding	**25**	4	1	3	-22
Creative agency	0	0	6	18	+18
Emerging-new activity system	0	0	5	13	+13
Motivation	11	1	0	6	-5
Locating and using resources	0	8	5	4	4
Convergent thinking/evaluation	3	2	3	8	5
Tolerance of ambiguity	0	2	1	11	11

[a]difference in code frequency count between Journal IV and Journal I

This data showed drops in the codes for exploring project options (-34), empathy/human-centeredness (-26), problem finding (-22), and motivation (-5.) These numbers indicated that participants considered project options mostly during the beginning of the course, which was linked with considering other people (empathy/human-centeredness) and the problems (problem finding) they experienced as a method of identifying and choosing project topics. The drop of code frequencies for motivation indicated participants' motivation for project work was established early in the course as they worked to identify and select their projects for the semester.

This data showed rises in the codes for contradictions (45), tool exploration (25), creative agency (18), and feedback seeking (13.) Participants encountered an increasing progression of challenges in their work (contradictions.) They increasingly used design tools (tool exploration) and sought feedback (feedback seeking) in conjunction with prototyping. Participants reported increased feelings of creative agency, and almost exclusively when they reflected on their project work for their final journal entries.

The stacked bar chart in Figure 28 displays the combination of code frequencies found within each journal entry, and the total code frequency count across all four journal entries. This data display shows links between the early part of the creative design process (Journal I, week 3) and (a) using a human-centered problem finding approach to identify project topics and (b) the establishment of motivation for project work. The data also showed a link between tool exploration and prototyping that became prominent in week seven of project work. Also, the data showed that challenges (contradictions) did not become prominent until week seven and that participants remained focused on them through the remainder of the course and especially during the last week of their final reflective journal entries.

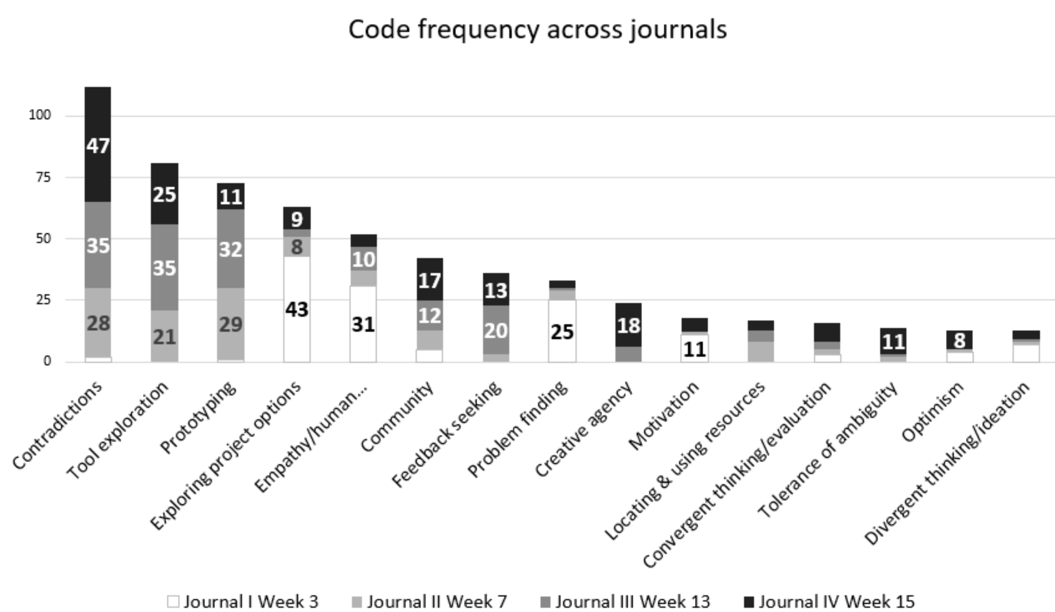

Figure 28. Code frequencies across journals and weeks

Rank ordering codes across a time series sketched a general shape of participant activity and developmental patterns of design abilities but was limited to the generalized activity. It shed light on *what* happened and *when* it happened but did not offer much about *why* and *how*. To explore the why and how questions, codes that intersected with the most frequently occurring codes were used to identify text for subsequent analysis.

To restate the “what” and “when” of the journal data set, Figure 29 shows the more frequently coded codes from participant journals and when they occurred in the time-series of journal entries. This high-level summary used findings within each set of journal entries and across the four-journal series.

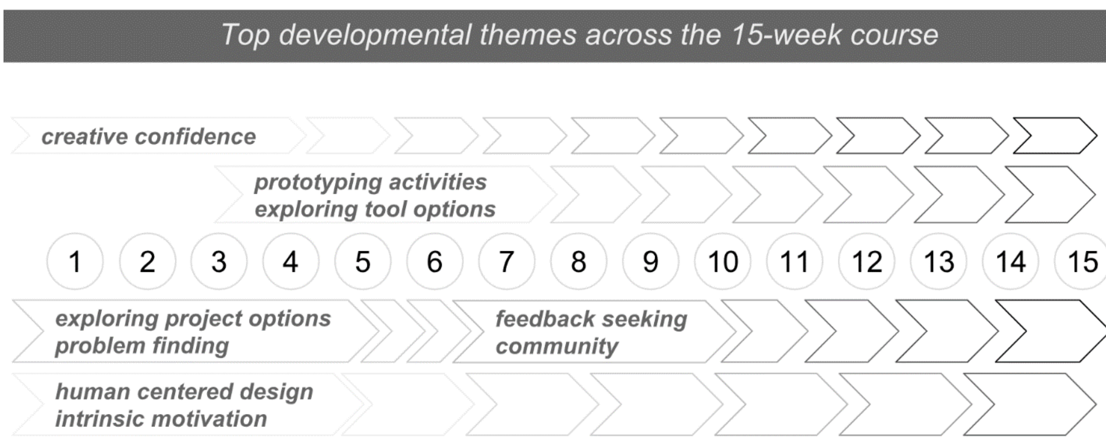

Figure 29. Top developmental codes across the 15-week course

Journal I, week 3. The first set of journal entries were submitted during week three of the course, and the code frequency for exploring project options indicated that participants were focused on choosing projects. An open-ended time frame was allowed for project identification. Participants were not rushed or given a list of project topics from which to choose. They *were* asked to choose project topics that were personally meaningful to them, and supplemental data showed that most participants did so. In response to the question, *Did you consider multiple ideas* *for your project? If so, how many?* (Survey form B), two participants responded with four project ideas, 12 participants responded with three project ideas, six participants said they had two project ideas, and four participants said they considered only one project idea.

When asked, *When did you first get the idea for your final project?* (Survey form B), participant responses varied between time and activity-oriented descriptions. Six participants said they got their project ideas two or three weeks into the course. Three participants said their project ideas came to them before the course started (e.g., “over the summer before class,” “years ago.”) Five participants got their project ideas during activities such as “watching online videos,” “walking down a street,” “tutoring a friend,” and “after a dinner with a friend.”

When asked, *When did you finally decide that idea would be your final project idea?* (Survey form B), participants replied again with a mixture of either time or activity-oriented descriptions. Eight participants indicated a few weeks, and two said they didn’t finally decide until mid-way into the course or later. The other participants described the following activities:

- After working on an extensive flowchart of how my final project (app) would be designed
- After we did the elevator pitch, and I got some feedback from my classmates
- writing the design journal
- when I completed workshop training to use 3D printer
- when I realized how much I loved shoes
- after talking to my grandma

The responses to these questions showed a range of inspiration and time taken to choose project ideas that indicated the project topics were personally meaningful to the participants.

The most frequently referenced codes in the textual data were *exploring project options*, *empathy*/*human-centeredness*, *problem finding*, *motivation*, and *divergent thinking*. All five of these codes overlapped the same or surrounding text segments, suggesting that they co-occurred, were related, and were contextually dependent. Table 33 shows the (a) top five rankings of code frequencies from Journal I week three and compares them with the (b) summed total of codes across all journals and (c) their rankings in the other sets of journal entries. Figure 30 shows the codes within the context of the course activity system. Codes from the current journal being discussed are in bold type. Parenthetical descriptors (e.g., *action*, *affect*) indicate if the code was classified as representative of action (observable, cognitive, or both) or of affective psychological states. These conventions are used for all subsequent tables that show code rankings across the four sets of journal entries.

Table 33

Top 5 Design Journal I Codes

Code	All Journals	Journal I Week 3	Journal II Week 7	Journal III Week 13	Journal IV Week 15
Exploring project options (action)	63	**43**	8	3	9
Empathy/human-centeredness (affect)	54	**31**	6	10	5
Problem finding (action)	33	**25**	4	1	3
Motivation (affect)	18	**11**	1	0	6
Divergent thinking/ideation (action)	13	**7**	1	1	4

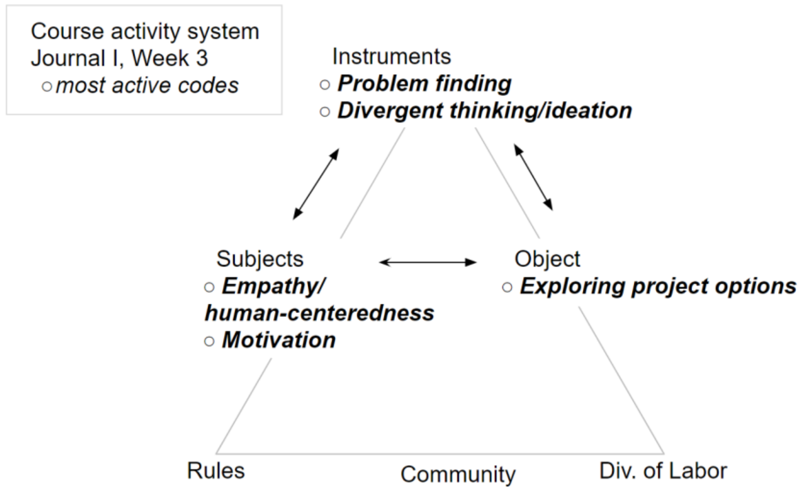

Figure 30. Course activity system Journal I, week 3

An ordinary world, disturbed. "The class wasn't what I was expecting when I signed up" (Eric, DJ4). Many participants did not know what to expect from this course when they signed up for it. Some participants wrote about past experiences with school that led them to expect a highly structured environment and exacting instructions for how to proceed. Students said their expectations were built over time, including elementary school and college experience. For some, school meant being told what to do. They *did* know the course satisfied the requirement for the upper-level elective they needed to graduate. Also, from the student bulletin, they might have read the course was about technology and how to use it in professional work environments. Some participants knew they would be learning about how to use technology in professional contexts, but it wasn't until the class began that realized the course design was project-based and required choosing projects.

So, the participants may have been surprised when they were asked to come up with their own ideas for what they would do all semester in this course—no less from an instructor with a background that included performing street magic in China and who used magic tricks to disrupt cognitive fixations and make connections to the creativity and design thinking literature. As students spent time choosing project ideas, homework assignments, and class activities focused on sketching, journaling, mind-mapping, idea generation, creativity, and design thinking. The instructor was well-prepared to provide supports for students' creative design process and understood the value of establishing a psychological tone for the course that was conducive to the expression of creative behavior. But as much as the instruction facilitated design creativity through project work, the ambiguity of undefined projects deeply challenged some participants. It led some to question their creative self-efficacy and ability to conceive, design, present, and deliver an original idea. One participant, who eventually created an online forum design to help employees freely express themselves in professional contexts, put it like this:

> The main challenge I would say that was difficult and important was thinking of a problem we wanted to solve. When you ask a broad generic question like "What kind of problem do you see around you?" it is very confusing on what to think about. Many of the students were afraid to talk because they were not confident in their own thoughts and ideas. The idea conception is where the first and hardest challenge came. I believe it is the most important one because it is at this phase, that we decide what to work on for the rest of the semester (student 19, DJ4)

At the end of the course, student 19 said his project for the course helped him get his first job at a software company.

It was not easy for some participants to commit to project ideas, which suggests they cared about the choices they made. Also, an important but frequently overlooked complement to divergent thinking is convergent thinking (Cropley, 2006), and this is where participants struggled in their decision making. Some worried their ideas were not feasible and imagined obstacles that might get in the way. For example, a participant who designed a creativity tool for writers of fiction nearly abandoned her idea "because it would be difficult to get copy write on each of the stories that could be created by the algorithm" (student 11, DJ1). She liked her idea but believed it was too impractical. The idea was inspired by childhood memories and reading with her father. When participants wrote about exploring project topics, they often thought of both their personal experiences and those of others, especially during the beginning of the course when identifying options and deciding what their projects would be.

The student who had trouble committing to her idea was able to resolve the contradiction, eventually. She continued working on the creativity tool for storytelling and used her final journal entry to reflect on her process:

> I remember writing my first design journal and questioning if the idea that I had at the time was even worth pursuing as my project for the semester. As we went step by step through concept maps, journey maps, paper prototypes, and finally a digital prototype I found that my original idea was more realistic that I originally anticipated. I had challenges with the technological aspects of this project, but in the beginning, I lacked confidence in my idea. (student11, DJ4)

For this participant, the in-class activities that supported creative design thinking helped her to persist with her idea and develop it. She said peer and instructor feedback were instrumental in helping her decide to pursue her idea.

An initial surprise and confusion characterized the first few weeks of the course because the mix of student autonomy and ambiguity contradicted most participants' expectations of school. The course was advertised as an opportunity to learn to use technology in a professional context, but the instructional methods having to do with creativity, design thinking, and choosing semester-long projects were surprising and did not match some participants' ordinary school experiences. With time, practice, and support for their creative processes, participants settled on project ideas and crossed the threshold: the next challenge—designing and building projects.

Journal II, week 7. Participants submitted their Journal II, week seven entries one week after presenting their project ideas to the rest of the class as "elevator pitches." Each student stood before the class and briefly described the problems or opportunities the project addressed, the people whom the project helped, and any initial ideas for the design and development of the project. As part of supplemental data gathering, I attended these classes and made informal observations. The pitches were each less than three minutes and presented in a casual way. Some students prepared presentation slides while others had none.

The instructor explained the elevator pitch guidelines to the class, which encouraged students to offer feedback at the close of each pitch. I noted these informal, voluntary feedback episodes helped to build a sense of group identity and community. In one case, a student's pitch contained very few ideas, and it seemed clear to me the student put minimal thought and effort into the pitch. The awkward moment of silence following such a minimal pitch was met with respectful, supportive feedback from some class members who contributed genuinely helpful ideas to the presenter. I detected no disapproving tone in the room and no indication from the instructor that the pitch was insufficient. An open, relaxed, and respectful attitude characterized the psychological tone of the room, which was supportive and devoid of explicit performance assessment.

Several participants wrote in their journals that presenting their ideas to the class was meaningful, increased their motivation, and clarified their ideas. For example, one participant used feedback from her pitch to iterate her design, "After completing the elevator pitch activity I realized some little aspects of my project that I feel like I need to go back and refine, just so that way I can create the best experience for my audience" (student 11, DJ2). Other students, who were unsure of their ideas beforehand, said they gained confidence in their project ideas after presenting and receiving feedback in class.

The Journal II, week seven entries showed most students were clear about their project ideas and working on the design and development of them. The codes for prototyping (1 to 29) and tool exploration (0 to 21) rose and indicated a shift in energy from exploring project options (43 to 8) to prototyping. Table 34 below shows the top codes that emerged with the second set of journals. Figure 31 shows the codes within the context of the course activity system.

Table 34

Top 5 Design Journal II Codes

Code	All Journals	Journal I Week 3	Journal II Week 7	Journal III Week 13	Journal IV Week 15
Prototyping (action)	73	1	**29**	32	11
Tool exploration (action)	81	0	**21**	35	25
Community (action)	42	5	**8**	12	17
Exploring project options (action)	63	43	**8**	3	9
Locating and using resources (action)	17	0	**8**	5	4

Note. Codes omitted from ranking: Contradictions

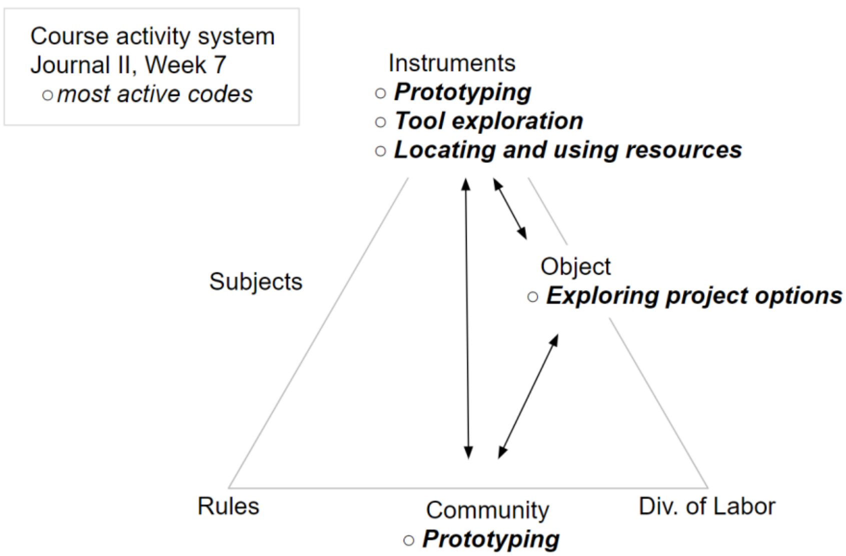

Figure 31. Course activity system Journal II, week 7

Projects chosen, what next? By week seven, project topics were settled, and participants used prototyping and software design tools to model project ideas. Some participants had yet to clarify a project beyond “a lot of unorganized ideas” and had plans to identify the right prototyping tools, such as hand sketching, software, and physical modeling. Most participants struggled with the “learning curve of certain apps and websites,” and once they learned to use digital design software, they needed to learn about user interface (UI) design. Many participants used hand sketching, and index cards to begin prototyping. Some reported the hand sketching and index cards helped them transition to digital tools, while others said they had difficulty with the transition. Most of the participants making 3D printed products had difficulty scheduling training at the campus 3D labs. Their schedules did not usually align with the campus 3D labs' training times, yet training was required to use equipment in the labs. Participants were also challenged by their misconceptions about prototypes, defining the scope of projects, and procrastination.

The excitement of having new project ideas was met with the challenges of representing them. As one participant explained, "I have the basic understanding of what I want to accomplish, but actually designing it and figuring out how it will work best can be a little frustrating." And, a successful first prototype was met with realizations that initial ideas required revision, "During my prototyping experience, I've realized that it will be difficult to include all of the features I originally thought to include." Making thinking visible with prototyping was a key part of the design methodology students practiced. Both the technical challenges of prototyping and the challenges of moving from abstract design ideas to the concrete representations of them characterized many participants' activity, according to these journal entries.

Stubborn misconceptions arose about the function of prototypes in the design process and a belief that prototypes and final projects needed to be fully functional troubled some participants, even though the syllabus and instructor emphasized that final projects were not expected to be functional. One participant wrote, "I have no software or engineering capabilities to make a real prototype for my project." Another student said, "Knowing how to code such an extensive application is quite tedious" was a major challenge in his project work. Another student thought a full program would need to be written in either MatLab or the Python computer language "before attempting to build a physical prototype." Another student believed that "most app design tools require a Mac computer." This was odd since the popular choice for a design tool was the web-application Marvel App, which was a browser-based, OS independent digital prototyping tool. It was unusual that misconceptions like this persisted at the mid-point of the course, and the issue was discussed by only three participants. All three were male, 22 or above, and majored in finance or mechanical engineering. Ultimately, all three participants completed their final projects and indicated satisfaction with their experience in their final journal entries.

Participants increasingly used peer and instructor feedback to overcome challenges in their project work, as was reflected by the steady increases in references to the community in the journals. At times the instructor provided feedback, such as when a 21-year old business major was learning to use software to prototype a mobile app design, wrote, “I was able to create a prototype for my design tool with the help of my instructor” (student18, DJ2). Other times peers provided feedback, such as when this 19-year old sophomore working on a parking app design wrote, “I have gotten feedback from several people up to this point and have been brainstorming ways to make use of their feedback” (Scott, DJ2). For other students, it was watching peers present ideas that helped, as when a 20-year old junior majoring in business wrote, “As for the design of my prototype I think a really useful tool that I could use it the tool the Marie showed the class” (Alex, DJ2). In addition to the feedback sessions, students regularly rotated, and all shared their project progress and their tool learning experiences with the rest of the class.

When exploring project options, most students shifted form exploring possibilities for project topics to exploring options within their chosen projects. For example, one participant considered adding a mobile app to his idea for a physical cleaning product to give the target audience a more interactive, gamified experience. Participants also began to expand the way they approached design work. In the previous example of the cleaning product, the participant’s use of specialized language such as *target audience* provided indicated he was integrating human centeredness into his design methodology, “I also have considered making my product more interactive. I feel like a simple cleaning app to go with it may be beneficial and increase my target audience" (student10, DJ2).

Many participants found paper prototyping enjoyable and that it eased the transition into software design tools. For example, a 19-year old sophomore majoring in communication and speech disorders was more comfortable beginning with paper and hand sketches:

> For my prototype, I am going to start with a paper design for the app. There are a lot of different options for when I decide to prototype my app online, but I'll probably use the one we have discussed in class. (Julie, DJ2)

For some students, paper prototyping was helpful for moving their design process forward without worrying too much about learning to use digital prototyping software. For example, a 20-year old psychology major working to design a creativity app to support storytelling wrote,

> I have a general idea of how to create hand drawn prototypes, but I am not really familiar with types of software that can help me create a prototype on the computer. I think moving forward the creation aspect on the computer is my biggest concern. (student11, DJ2)

At week seven, students learned to use design tools and to prototype their design ideas. Initial challenges of the unusual course format and selecting projects receded, and new challenges of tool learning and using prototyping as part of a design process became the focus of student activity, according to the participant journals.

Journal III, week 13.

Prototype presentation day. Participants submitted their Journal III, week 13 entries four weeks after they presented their prototypes in class during week nine, which offered me the opportunity to check in on participants' progress since their "elevator pitches" during week six. I attended the "prototype presentation day," spoke with some of them about their work, and conducted informal observations that added to the supplemental data in this study. The instructor began class with a brief presentation about error-tolerance design before introducing some guidelines to help students provide feedback to each other on their prototypes.

Next, the instructor distributed printed handouts to students to facilitate peer feedback. The handouts outlined a three-step procedure of talk, observe, and listen for conducting project feedback. First, peers described their projects to their peer reviewers. Second, the peer presenters remained quiet while the reviewers made notes. Third, the reviewers provided the peers with project feedback. After three minutes elapsed, the students switched roles and repeated the procedure. After this, students found new partners and repeated the process. Students were encouraged to receive feedback from at least three different classmates. When the activity began, I joined in and participated as possible.

A 20-year old junior cellular biology major explained some intricacies of glucosamine and joint health to me and showed how her design was a preventative care measure inspired by the idea of birth control implants. Her project involved 3D printing, and she told me there were multiple 3D printing labs on campus, but most required scheduled training sessions before access to equipment was granted. She had difficulty aligning her schedule with the available training times but was able to discover one of the labs did not require scheduling because it had full-time training staff and accommodated walk-ins. Her career goal was to be an orthopedic surgeon, and she enthused how excited she was to work on an idea of her own that related to her passion and career goals.

A 21-year old senior finance major showed me his idea for a parking solution involving “genetic license plate recognition.” He used Adobe XD software to create the prototype and Pixlr software to create the logo. He told me how his friends outside of class, and his classmates recommended he incorporate social features into his design. The next student was a 20-year old biology major working on an idea he had since childhood. Part of the prototype is shown below in Figure 32.

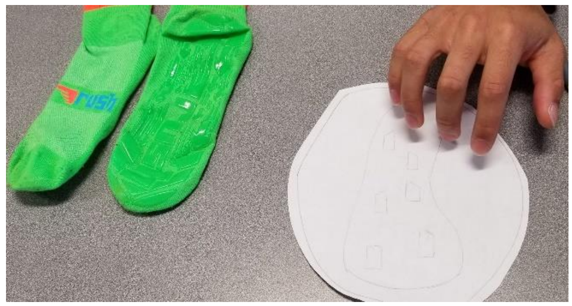

Figure 32. Student prototype - gamified household cleaning

It involved accomplishing cleaning chores via foot attachments, and he currently working on gamifying the process with the inclusion of a mobile app, which he used Adobe XD to prototype. He told me the idea was from his childhood when he imagined attaching mops to his feet would make cleaning easier and more fun. He was surprised to have the chance to work on it within a college course. He was also surprised that he was able to learn and use digital prototyping software.

A 23-year old junior mechanical engineering major showed me his design for a specialized calculator. It was a learning aid that displayed whole calculation processes for users and was something he wished was available to him during the early part of his studies. He wanted to make a calculator that would help new students in his program. The prototype is shown below in Figure 33.

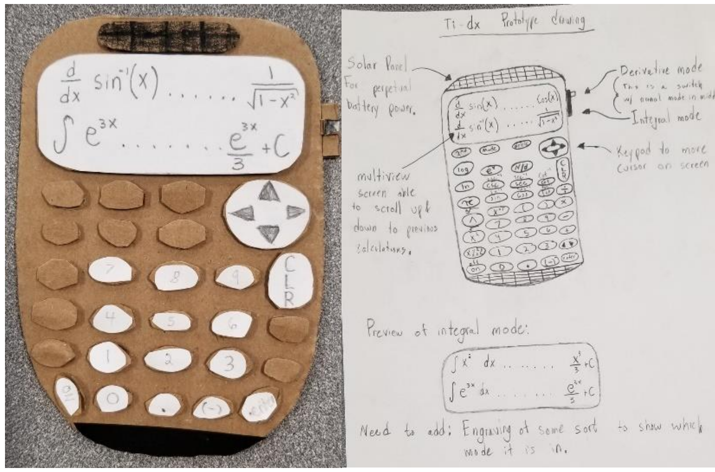

Figure 33. Student prototype - specialized calculator as a learning aid

He repeated what the cellular biology major told me earlier. It was exciting to combine his interests with course work. The course was a pleasant surprise for him. “I no idea it’d be a design class,” he said. Next, a 20-year-old junior management information systems major showed me his prototype of a mobile app to help college students find compatible roommates. This student was experienced with Adobe software and proved it by walking me through a sophisticated workflow he used with the suite of Adobe products. He did not use paper prototyping and preferred a purely digital workflow. His prototype is shown in Figure 34.

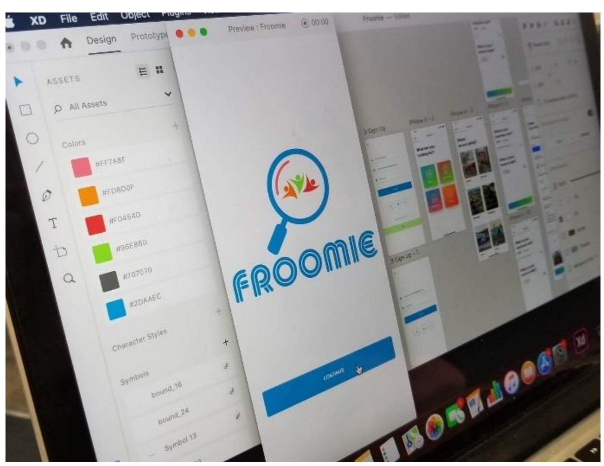

Figure 34. Student prototype - roommate finder digital prototype

Another mechanical engineering major told me about his idea for solving the problem guitar players encounter when their hands stick to the neck of the guitar. The idea was inspired by his bassist friend's medical issue that a glove ameliorated, and now the student was focused on finding the right materials to make the glove work. This project idea was much less developed in comparison to the other projects I saw.

The course instructor introduced me to 21-year old management information systems major and his prototype of an opposed-piston engine design. The student explained the horizontal design was unconventional and finding people with the technical knowledge necessary to provide helpful feedback was a problem. His prototype is shown below in Figure 35.

Figure 35. Student prototype - opposed-piston engines

To help the student get feedback on his design idea, the course instructor recommended the student reach out to a professor in his department and ask for some feedback on his prototype. Next, a 21-year old senior consumer journalism major showed me her prototype of a mobile app to help older tourists. The idea was inspired by the troubles her grandparents experienced when traveling. She designed individual screens with 3x5 inch index cards and a pencil and planned to convert them into an interactive digital prototype. The card-based prototype is shown in Figure 36.

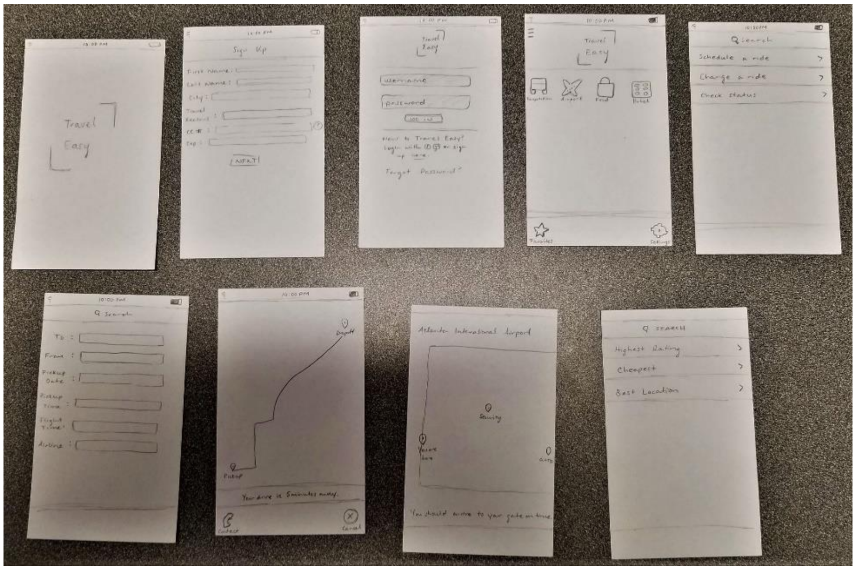

Figure 36. Student prototype - index cards

A range of interests and prototypes were shared this day. Students seemed to have project ideas that held personal meaning, but most students were exuberant in sharing while a few were reticent with their ideas and progress. The diversity of ideas and meanings they held for each student made the biggest impression on me. The feeling of enthusiasm and optimism was palpable in the room, which suggested to me that most of these students were excited, having fun, and engaged with their project work.

Breaking through, building ideas. This second to the last set of journal entries was submitted during week 13 of the course, two weeks before final projects were due. Some participants were at ease with their progress, others were reassembling their ideas into finalized versions, and all were coming to terms with the end of project work. According to the code frequency counts from Journal III, the actions most associated with this work were tool exploration, prototyping, and feedback seeking. References to community continued to rise, and the code frequency for empathy/human-centeredness increased. The notable increase was with the feedback seeking code's frequency, and its coded text typically overlapped with the prototyping and community codes. These top five code frequencies found in Journal III week 13, shown in Table 35, and Figure 37 shows the codes within the context of the course activity system.

Table 35

Top 5 Design Journal III Codes

Code	All Journals	Journal I Week 3	Journal II Week 7	Journal III Week 13	Journal IV Week 15
Tool exploration (action)	81	0	21	**35**	25
Prototyping (action)	73	1	29	**32**	11
Feedback seeking (action)	36	0	3	**20**	13
Community (action)	42	5	8	**12**	17
Empathy/human-centeredness (affect)	52	31	6	**10**	5

Note. Codes omitted from ranking: Contradictions

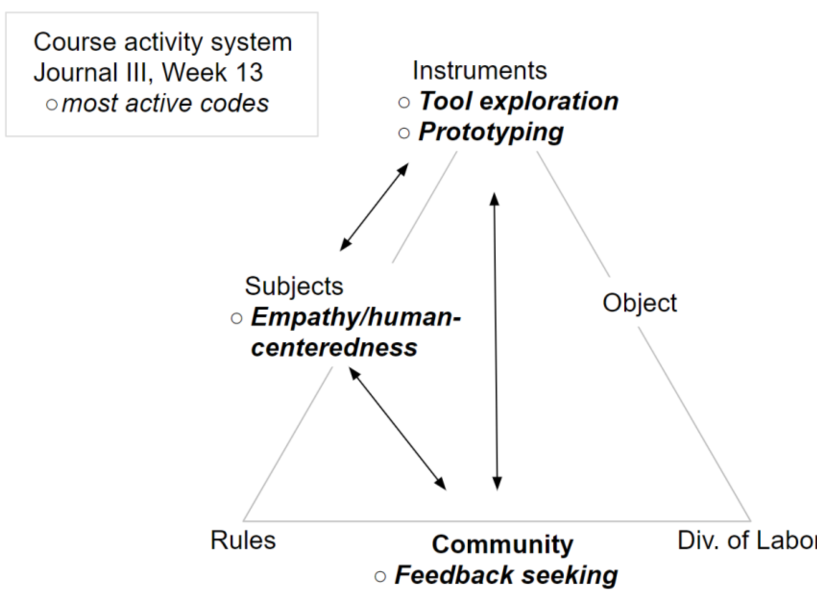

Figure 37. Course activity system Journal III, week 13

The contradictions code was omitted from the journal rankings because its function as an "organizational category" was to collect references to project challenges for the second stage of analysis where its intersecting codes were used to characterize the challenges and highlight the evidence for them. This code tied with the code for tool exploration (frequency: 35) as the highest-ranked code in this set of entries. The qualities of the contradictions participants described fit within the five categories of (1) technical, (2) prototyping, (3) project management, (4) human-centered design, and (5) combining theory with practice. These categories are summarized with Figure 38.

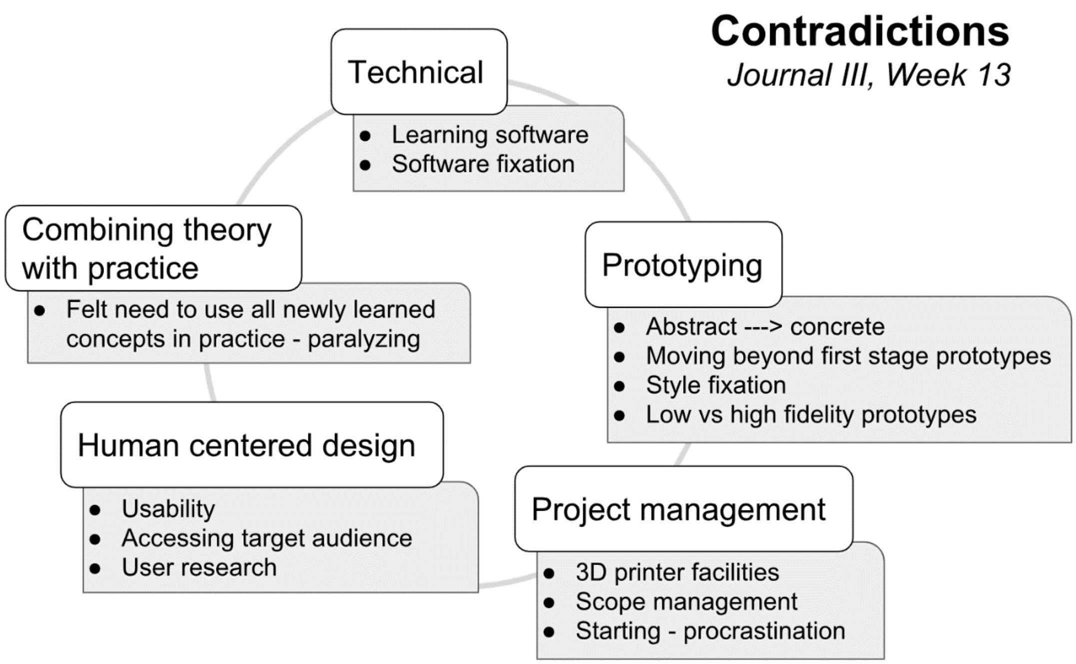

Figure 38. Journal III, week 13 contradictions

The challenges participants wrote about in this journal entry varied. Some had difficulty with "figuring out the features" (student 3, DJ3) for software or feeling they should choose complex over simple prototyping software because the latter might not offer a "good enough representation of what I want my app to be" (Scott, DJ 3). This related to misconceptions that led some participants to worry their prototypes needed to be high fidelity or fully functioning. One wrote, "I am an engineer not a programmer" (Student 20, DJ 3) and questioned if he would be able to do the "actual programming of this system" (Student 20, DJ 3). The difference between what participants needed to do and what they imagined they should do was a dilemma for a cluster of students.

Participants who used 3D printers for their project work were challenged by the logistics of scheduling and "trying to find the time to get to the makerspace" (student 15, DJ 3) for their project work. All participants needed to manage their project work, but the ones who chose to use the 3D labs added an extra layer of complexity. Another cluster of participants felt blocked by the lack of a "real" or authentic target audience for testing their prototypes, a problem that was amplified when the participant's project topic involved specialized domain knowledge that peers in the course did not have. Resolving the difference between the imagined design idea and the concrete prototype of that idea was yet another area of challenge. This tension between the abstract and the concrete related to one between theory and practice, when a participant wrote about her design process as theory-laden: "I am starting to become overwhelmed with the application of the principles we are learning and how to incorporate them into my app without causing the app to take an outrageously long time to complete" (Julie, DJ4). *How* participants perceived their challenges was a key part of their dilemmas.

How did participants work through the challenges? The coded texts for tool exploration, prototyping, feedback seeking, community, and empathy/human-centeredness overlapped extensively and seemed to be grounded in prototyping actions happening within the course community. Phrases like "seeing and watching how people interact," "let others try out the design so that I can find any flaws," and "letting my target audience guide my design" reflected the prototyping and feedback seeking actions that characterized much of activity reported in this set of journal entries.

Participants used their peers for design guidance by seeking feedback. In this way, prototyping, empathy/human-centeredness, and the community became tools that participants used to iterate and refine their design ideas. These interactions were the newly learned design methods participants used to surmount the challenges they faced. A typical example was a feedback cycle that moved design process forward:

> Additionally, talking to my classmates about their methods of prototyping has helped me get a better grasp on the project at hand. For instance, I have had success with the Marvel App after getting help from classmates. With the Marvel app, I now know what I want my app to look like aesthetically, so that is definitely a success! (student 6, DJ 3)

Feedback seeking also went beyond the classroom. Many participants gathered feedback from friends and family outside of class, “I continue to ask friends and family for their opinion on what should be included in the app” (student 28, DJ 3). One participant built a 3D model for field testing, “I have developed my concept into a 3D model, and I plan to begin testing the effects of the Fresnel lens on a 10W solar panel to provide a proof of concept” (student 9, DJ 3). The culture of prototyping that developed in the course used human-centeredness and feedback as tools and some participants extended these actions to friends, family, and experimental field tests.

The participants who were frustrated by tendencies toward perfectionism (e.g., the felt need to fully program the prototype, the felt need for high fidelity prototypes) came to terms with their unrealistic expectations and were mostly satisfied with what they made. One participant put it like this:

> Some of the major struggles that I have been running into is there is so much detail goes into an app like this and for me to get a full prototype of everything I want my app to do it would take a very very long time. I have found that taken

> step by step it is not too bad and that my prototype does not have to be perfect. (Alex, DJ 3)

Participants made design choices, delivered projects, and learned about themselves while gaining experience in delivering projects. Decisiveness required confidence, which could be heard when participants wrote about successes in their project work. For example, “As my project has progressed, I have started to feel more confident in my design” (Julie, DJ 3), “After trying multiple websites and apps, I have gotten a better feel for prototyping and app building” (student 6, DJ 3), and “The biggest success at this point is knowing the exact goal of my project, and knowing that I will be able to reach it” (student 1, DJ 3). Feelings of confidence emerged as students made design choices.

Journal IV, week 15. Course work ended, and students presented their projects at the “final project showcase” during the last class meeting. At the close, an engineering major asked to stay and show the course instructor and me his plans for a new type of solar lens and results from his most recent tests. After he hurried away to his next class, my impression was how project work for this participant was exciting and so well-tailored to his intellectual interests and career goals. It did not feel like school. Was it like this for all the students? The instructor and I packed up leftover snacks, left the room, and closed the door. While leaving the building, we talked about what did and didn’t seem to work, why some students seemed more engaged than others, ways to improve the course, and how to integrate it with the ongoing research. As was usual when we met, we lingered in this conversation until we were out of time.

Participants submitted their final journal entries after the final project showcase. Journal IV was the last assignment, and on average, students wrote more in this entry than any of their others. They were asked to specifically reflect on their design processes, on the biggest challenges faced, and on the most valuable lessons learned. The previously established codes of tool exploration, community, feedback seeking, and prototyping continued to be the most referenced.

The frequency of creative agency codes stood out as the biggest gain, and its surge was noteworthy as it was nearly non-existent in previous entries. Table 36 shows the top five codes in Journal IV week 15. Figure 39 shows the codes within the context of the course activity system.

Table 36

Top 5 Design Journal IV Codes

Code	All Journals	Journal I Week 3	Journal II Week 7	Journal III Week 13	Journal IV Week 15
Tool exploration (action)	81	0	21	35	**25**
Creative agency (affect)	24	0	0	6	**18**
Community (action)	42	5	8	12	**17**
Feedback seeking (action)	36	0	3	20	**13**
Prototyping (action)	73	1	29	32	**11**

Note. Codes omitted from this ranking: Outcome, Contradictions, Emerging-new activity system

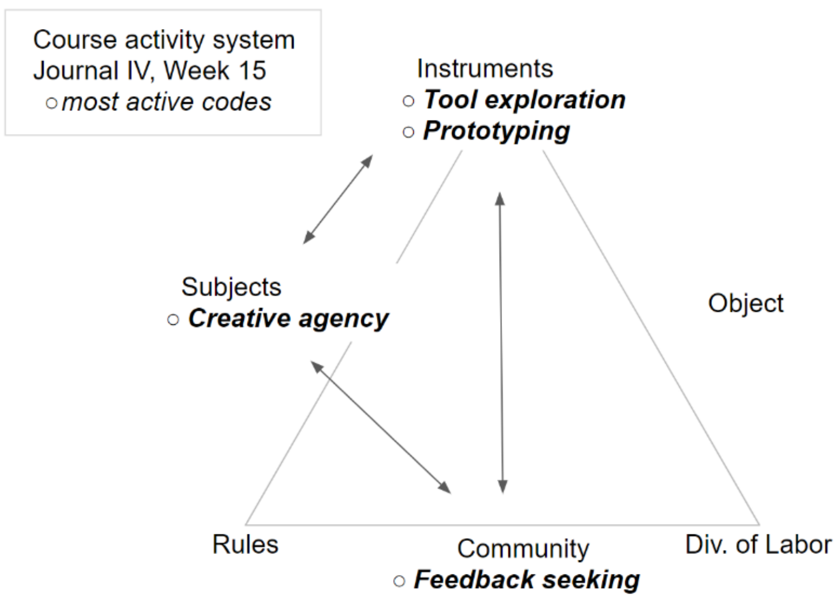

Figure 39. Course activity system Journal IV, week 15

When filtering Journal IV codes for *outcomes*, the creative agency code was even more pronounced. Recall that codes like outcome, contradictions, and emerging-new activity system were classified as organizational categories, which meant they were used to filter data broadly and to reveal intersecting codes classified as action or affect (e.g., tool exploration and creative agency.) Table 37 shows characteristics of the outcomes participants wrote about the most and how much the counts for those codes changed across all four journal entries.

Table 37

Journal IV Outcomes

Code	Outcomes Journal IV	Frequency Change Journal I to Journal IV
Creative agency	17	+18
Tool exploration	15	+25
Emerging-new activity system	12	+ 13
Community	8	+12
Optimism	7	+4

Reflections. The journal IV data emphasized a cluster of actions (i.e., tool exploration, feedback, prototyping) and affect (i.e., creative agency) that characterized participants' activity in the course. These actions and affect supported the course community, which reciprocally supported the actions and affects in what appeared to be an expanding activity cycle. All these factors framed participants' responses when prompted to write about the "learning" in their course experience they thought to be most personally meaningful. The newly appearing code for creative agency referenced text segments that described new feelings of creativity and confidence in using tools, design methods, and interacting with peers within the context of project work.

When participants wrote about what they did, tool use was the most common theme. Some were surprised by their ability to use design software, as the 20-year old senior biology major who designed a gamified cleaning system wrote, "[I] learned how to use tools that I would not have ever imagined being proficient with." Similarly, other students were intimidated by the prospect of using design software to deliver prototypes. The 21-year old senior communication and speech disorders major reflected:

> Early in the semester when we were shown a prototype of an application from a student's final project, I was intimidated. I thought that it looked impossible to make and difficult to learn how to use different tools to even begin designing. I was stressed that I could not perform adequately because I am not the best at technology. (Student 6, DJ IV)

After spending time to play and practice with her choice of prototyping tool, she was more at ease. Her tool use "became more fun," and she felt "confident in [her] abilities." For her, tool exploration involved a mixture of "practicing and watching tutorials" and "talking to my classmates about their methods of prototyping." The tool exploration code also referenced support from the course instructor, as when a participant said he helped her to add "more features to the app to make it useful to users" (Student DJ IV).

Participants also became critical of tools and of how they were used. For example, the 21-year old senior finance major who prototyped a parking app reflected, "There are several templates that are downloadable, however, like I saw with my original prototype, it makes it easy to just use these templates, and then you lose touch with your original idea that you began with." Some participants found a tool's learning curve stalled their creative process. The 20-year old junior psychology major who prototyped a creativity tool initially "felt like [she] had to use Adobe XD" but was able to identify alternative tools that allowed her to complete the final prototype and to lift the "stress that was coming from [the final project requirement]" (student 11, DJ IV). Journal data showed a critical practice for tool use that involved identification and discrimination within software application feature sets and between software applications.

Many of the code references involved creativity. The instructor went to great lengths to encourage and support creative behavior in the course, so it was unsurprising that participants wrote about the subject. But the interesting part of the findings was in how participants described creativity in their work and how it became meaningful to them. Participants repeatedly wrote about increased feelings of creativity within themselves, in others, and in doing project work. A recurring theme was that creativity was not a fixed trait. A 25-year old senior business major who designed an online forum for free expression in professional contexts said, “I learned that creativity is just like any other skills, it can be refined and improved through practice and experience” (student 19, DJ4). Another participant said some of the most valuable things she learned was that creativity “Does not stay the same,” and that “you can be as creative as you want throughout life” (Student 3, DJ IV).

Other participants wrote about how doing project work helped them think of creativity differently than they had before the course. One participant said that before the class, she “Never really saw [herself] as a creative person,” but “just good at numbers.” She reflected that making her app and “all the other activities in the course…helped me shape myself into a creative individual, which I am so grateful for” (student 21, DJ4). The 20-year old junior cellular biology major reported the same feelings and added, “I am proud of it” (Student 26, DJ IV). Another participant linked tools and technology with creativity and said knowing he could increase his “creativity levels” would give him confidence in the future when finding the right tool to help him express his creative ideas, “No matter what I’m trying to do” (Student 2, DJ IV). Another participant wrote about the pride she felt in “my creation” (Julie, DJ IV) and a new trust her ability to create something that “far outweighed” any of the doubts she had about her creative ability earlier in the course.

Community. Participants often described their experiences with prototyping and feedback seeking within the context of the course community. In this sense, the course community functioned as a tool that was used to assist participants’ creative design process. Additionally, participants described the community in terms of their interactions with peers and the course instructor as well as in terms of personal communities they brought into their course work. In this sense, the participants experienced community as at least two interconnected dimensions, the course community, and the outside community. Figure 40 shows how the two dimensions of the community came together for participants in their project work.

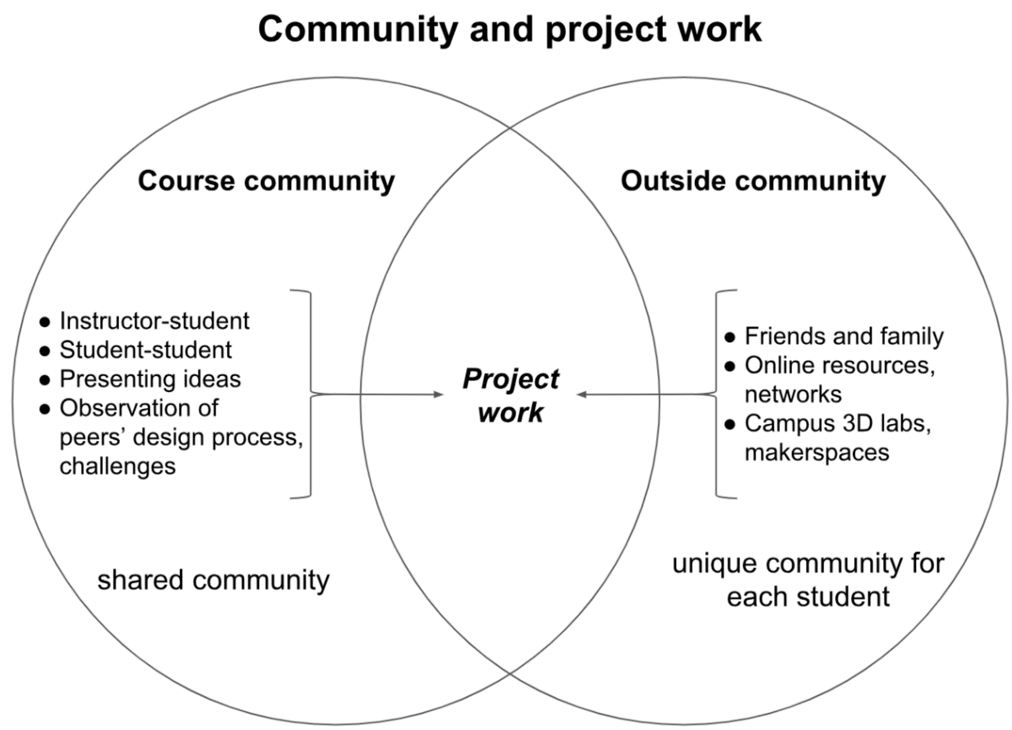

Figure 40. Integration of in and out of class community spaces

Many of the participants wrote about how they experienced community when reflecting on their project work in the course. The actions they wrote most about was the feedback they received from each other and the course instructor. Some participants said peer feedback strengthened their motivation to work on projects. An engineering major wrote that people liked his idea and told him to "pursue thinking about engineering more concepts like [his] project" (Student 22, DJ IV). A psychology major said that it wasn't until she pitched her idea to the class and received "both positive and negative" feedback that she "started to gain some confidence in [her] idea" (Student 11, DJ IV). A community where ideas could be presented and feedback could be received were significant aspects of the course for these participants.

Participants explicitly named the course instructor as helpful and supportive whenever they had challenges and asked for help. They appreciated the instructor's help with developing prototypes, adding features that made projects more "useful to users" (Student 18, DJ IV), making "big changes…but also little details" (Student 10, DJ IV), and his willingness "to help with any roadblocks" (Student 26, DJ IV). Throughout the journals, references to the course instructor were consistently positive, and it seemed clear that he actively supported the prototyping culture that he instigated, and that the participants integrated into their expanding design methodologies.

Other participants wrote about making changes to their prototypes based on peer and instructor feedback, as when a 21-year old finance major explained, "The more I reached out to my peers and asked for their input, the more varied and interesting the uses I discovered" (Eric, DJ IV). A 21-year old senior management information systems major emphasized how "input" from others was useful and helped her create "an idea even better than the original" (Student 18, DJ IV). Sometimes the feedback challenged participants and created tension because there was no clear fix for certain design problems, as when a 25-year old management information systems major said his "Top stress had to be in trying to come up with a solution for [some of the] feedback [he] received" (Student 19, DJ IV).

The 20-year old junior psychology major who prototyped a creativity tool for writers characterized her experience with the group in this way:

> Even though every single person in the class was given the same assignment we all used our previous life experiences and interests to create different project ideas. I found this valuable because it really showed how collaborating with others can lead to more refined ideas. (Student 11, DJ IV)

The evidence showed that sharing activities like prototyping and feedback helped grow the community which in turn helped participants expand their creative design ability from individual to collective orientations.

Journals overview. The four sets of journals showed it took a few weeks for participants to settle upon their project topics and the design tools they used. During this time, the journals also showed a link between these project choices and the setting of participants' motivation for project work. With projects and toolsets settled upon, it then took another few weeks for a multi-dimensional community to form. As the community took shape, it became a source of support for project work, particularly for tool exploration, prototyping, and feedback seeking. At the conclusion of the course, participants often wrote about feelings of increased creativity, appreciation for the design methods they practiced, and more confidence in their ability to use tools for creative design work.

Figure 41 shows a history of activity for the course. Each triangle represents the most frequently assigned codes within each of the four sequential journal entries. The codes are positioned in their relation to the standard activity system components and are set in bold type.

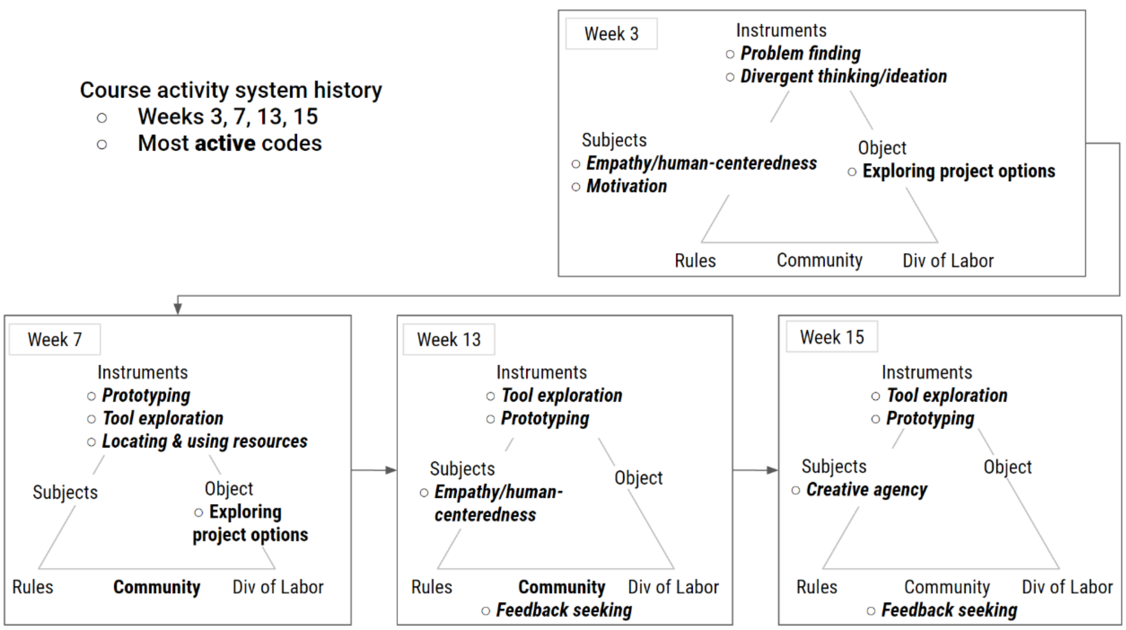

Figure 41. Course activity system history based on journal data

Interview Data

The five participant interviews confirmed and added depth to the data gathered by the journals. Of all the codes, the community was emphasized the most and extended in a few directions. All the interviewees talked about their inspiration for project work in terms of the course community, their personal community of family and friends, and memories of a community (e.g., family and friends) that reached as far back as early childhood.

Eric. Eric was a 21-year-old junior finance major. He designed a music recommendation system that catered to “music and tech lovers” that used a wearable wrist device to detect heart rates and make suggestions. His parents were fans of music, and he recalled stories about his dad, who once owned and operated a record store. Ever since Eric was a high schooler, he liked to tinker with audio equipment and said he was the one his friends asked for advice about music and technology. Eric was a “big music guy” and listened to “a lot of different things.” He especially liked to match specific kinds of music with the various activities he enjoyed. “Having music to kind of suit my, my need at that moment is important.” He thought music could be used to improve people’s quality of life and designed a system to make it happen. Eric’s project inspiration came from multiple sources in his life and was driven by a desire to open peoples’ minds to the innovative ways music could be used.

Eric’s described the different challenges he found in his project work. The first he mentioned was “how to choose what kind of music,” which led Eric to “entertain theoreticals” and the dilemma of gaining access to a full database of music, negotiating licensing agreements, and compensating the original artists. After talking about this problem for a bit, we eventually agreed to leave it and move to other challenges. A challenge he found in his design process was “trying to design something and be constantly changing and evolving.” He said ideas were easy to visualize but representing them took “a lot of time and patience” and required an ability to “forgive yourself for having bad ideas.” He was used to “bailing” on ideas that didn’t work and said, “It's important to be constantly changing and failure is an opportunity to be better.” These attitudes toward the design process helped but didn’t resolve the tension between the amount of time it took to generate prototypes and how quickly his ideas changed. The conversation about prototyping led us to talk more about his prototyping process.

Although Eric was able to learn and use basic prototyping software, he greatly preferred to sketch his design ideas using a ballpoint pen and index cards. He described the specific kind of ballpoint pen he liked, and it was clear from looking at the sketches that Eric put a lot of effort into them—they were some of the most elaborate drawings in the group. However, sketches did not constitute a “working prototype” for Eric and after a point, seemed to limit his design process. As Eric mentioned earlier, making changes to ink and paper prototypes was very time-consuming. Classmates and friends understood and liked his ideas, but Eric wanted to move beyond sketching, and even when he scanned those sketches into prototyping software and made them interactive, he wasn’t satisfied. He wanted a truly functional, working prototype. He wanted it to look and function like a real app. When asked about design tools, the brisk pace of the previous conversation slowed.

Interviewer:	Cool, well, let me switch, uh, angles here and ask you a little bit about the tools that you're using. Like...
Eric:	...yeah [exhales, seems a little frustrated]...
Interviewer:	You know, the, like the actual...
Eric:	...design tools?
Interviewer:	Yeah.

Why was Eric unsatisfied with his progress with design software? Earlier in the interview, Eric described an alternate project he considered. It was a way to sketch ideas in the most frictionless way imaginable. As a person who has many ideas, Eric was frustrated even with pen and paper. “It’s bulky… I don't always have a pen and paper on me when I'm walking around like through the streets, and I think of something…” He wanted a way to record ideas where there was “no gap…even something like as small as like a ring on your finger...or you could...draw or visualize an idea or anything- really just like a whiteboard anywhere was what I called it. You could just write in the air…” Eric’s favorite conventional way of sketching was the whiteboard. He liked ideas to be unhampered by their representation, and he liked to be able to change them as organically as possible. His ideal vision of a prototyping method seemed related to his frustration with using design software.

Eric easily learned and used Marvel App prototyping software. Although he realized this helped present ideas, he also felt there was no real benefit in terms of “ease of design.” He wanted drag-and-drop design software that allowed designers to “drag-and-drop and draw all in one” and add features but said that kind of software was either very expensive or beyond his ability to use. Given these beliefs, Eric stuck with his strong preference for pen and paper. I proposed using a pencil might allow changes to happen more quickly, and Eric said, “I use pen simply because [laughs] I liked the way it writes better than pencil, I mean, and it gives you a sharper design.” For modeling his ideas, Eric used the methods he enjoyed the most. He liked the immediacy of sketching and the aesthetic of ink on paper.

In any case, Eric’s design process was positively influenced by prototyping and by the feedback and design conversations he had with classmates and friends outside of the course. Feedback resulted in design changes along micro and macro levels. Micro-level changes involved user interface elements, such as navigation. Macro-level changes involved the general focus on the app and a narrowing down of its focus. New feature ideas also resulted from design conversations and prototyping activities. For example, a classmate suggested an alarm clock that was triggered by changes in heart rate. Although Eric’s choice of prototyping medium may have felt limiting, feedback and design conversations in the class were not. Many of Eric’s design changes stemmed from interactions with classmates and friends outside the course.

When I asked Eric what he thought about the level of freedom he had in his project work he told me he liked it a lot. He enjoyed the freedom to select and design his project idea. He said his project could be whatever he wanted it to be, and the option to "jump ship" on ideas appealed to him. He said the clear directive of "make a product" was as specific as requirements needed to be. Most of all, Eric liked the tone of the course and classroom activities:

> I especially like how encouraging, like the professor and everybody else is of like, just being free to express your ideas or your, your once or your bad designs even, like having the confidence to do so...and, and make mistakes and that's okay.

I asked if it was unusual to have this much freedom of choice in schoolwork, and he told me that aside from some creative writing classes he had taken, there was not much opportunity "to attack problems in unconventional ways." Eric added:

> There's generally a, a method like [laughs] whether it's written down or it's told to you there's a way to do things. There's an expectation that you will do those things. And if you don't there's the kind of, observed ah [laughs], problem of a failure to succeed if you don't follow those steps or do through exactly as you're essentially told to.

He believed this problem was especially prevalent in middle and high school and valued having an opportunity in college to explore and develop his interests. He continued to talk about the controlled kind of learning experiences he had in school versus the freedom he experienced in creative writing courses and this one:

> …it's good for a lot of reasons, but it has problems because it, it's, it's training people to be good listeners and follow directions really well and think the same way and do the same things. And I feel like it robs a lot of people their individuality and, I think that doing stuff like this allows you to experience that a little bit more. You get to be creative and you get to figure out what you want, what you enjoy doing, what are your passions... Rather than just checking boxes and doing what everybody else is doing.

To close the interview, I asked if Eric would share his thoughts about design and what it meant to him. Eric believed design could manifest in many ways but was ultimately a creative expression to change the world:

> It's in its own way an artistic expression of what you're feeling, and what you see and what you want to change in the world. So, I think design is a lot of opportunities. I mean it's, it's super broad, but it should, design is an opportunity to make improvements on, on the world around us.

At the end of the interview, he said that during the course, he learned about having the courage to put ideas out there, which helped him improve his communication skills, creativity, and confidence.

Michael. Michael was 20-year-old junior management information systems major. He designed a mobile app that catered to "pre-college students" and helped them find compatible roommates. His idea was inspired by the stress his cousin felt when she transferred to another college and had trouble finding new roommates and a place to live. As Michael tried to help her with the search, he realized how difficult it was. He noticed how the existing apps and sites did a poor job of serving college students looking for roommates—they listed location and price but left out roommate searches and compatibility filters. Michael knew from his college experience how much better it could be when roommates were friends. So, he designed a roommate finder app and named it "Froomie."

Michael's experience and ability with graphic design software were far above average for this group of students. He explained to me how the "whole Adobe package" was installed on his computer and how he regularly used Photoshop and Premier not just for work, but in his daily routine just for the fun of it. He knew the Adobe package included prototyping software for building interactive mockups of mobile apps, Adobe XD, but had never used it, although he was "just curious to see what it was." When he talked about challenges he faced in the course, he said it was learning to use Adobe XD as his prototyping software because “the learning curve was fairly steep.” Learning the software was worth it for Michael. He was impressed with the high-fidelity output, and how it could be used by programmers as a precise guideline for building out his design. He had the experience and the incentive to learn a complicated piece of design software, yet Michael said learning to use it was one of the bigger challenges in his coursework.

I asked Michael to talk about his process of learning new software. His first step with any software was to learn the basics of the interface, what the buttons do, and what keyboards shortcuts to use. Whenever he had a question, he searched YouTube. He described this as “just trial and error and then going through YouTube videos” to find the answers. This process was enjoyable to him, and when we talked about other software, he knocked on the wooden tabletop for good luck and said he hoped to master Adobe Illustrator next. He showed the logo he made for his app, and it was impressive work. It looked like the work of a graphic design professional, and the aesthetic conveyed the “light” and “friendly” feeling he wanted people to have when using his app. Michael’s ability as a graphic artist was clear, and it was unsurprising he enjoyed using a system for software training of his own design.

Once Michael realized the course involved design work, he asked his father to mail his graphics tablet from home. He used the tablet to create the logo for his project but also just for the fun of it. “Like I can't even tell you how many times I'll just throw up Photoshop and I'll just start, just going through, throwing stuff down, just like I'm writing on paper really...” He often just did this for fun, and if an idea emerged “accidentally,” he might use it. He carried the tablet every day in case he had time to use it. Michael dedicated extended periods to drawing, and I asked him how he managed his time. He described his busy college schedule and how his time management system was organized by the week. Some weeks tests in other classes took precedence over project work, but other weeks he would put “20 or 25 hours into the project.” He went on to show me a specialized mouse leftover from his gaming days that had a high enough resolution for detailed graphics work. It seemed Michael would be happy to talk about design software and hardware for hours.

When asked how he felt about the level of freedom in the course, Michael said he found it to be stimulating. “It's not just…it's not boring. It's not just, ‘I'm going through cut and paste.’ It's like I actually have to sit down and think, ‘What's my next move gonna be like?’” Also, he appreciated the guidance supplied by prototyping activities and design journaling. He knew his abilities with design software were relatively advanced and noted that while he didn’t even do paper prototyping, he understood how the activity was helpful for others. “So looking around the room, it's helping people visualize like, ‘Hey, this is where I need to be headed,’ and getting feedback and you're like me, you're getting feedback.” For Michael, the freedom to make project choices was important and the supportive activities were helpful.

The biggest outcome for Michael was his realization that he was creative. He saw certain members of his family as creative but did not include himself. His course experience led him to adjust his self-image.

> Honestly coming into this class, even though…like…I've used Photoshop and like... I didn't consider myself a creative person... Like my, my mom has always been like the creative like the crafting ones in the family. But like I have like a cricket thing that like laser cuts things and they like make T-shirts and they make Christmas ornaments every year and all that stuff. So like I've just always pictured that as just like creative...but along the way it's like hey, maybe I'm creative in my own way. Video editing and Photoshop and the...even the stuff like that.

When I heard Michael say he used to not consider himself as creative, I was very surprised, given his long-term interest in graphic design and obvious talent. He told me how his idea of design shifted from “crafty and desingy…things” to “the whole picture of design” in “every aspect of life.”

When asked who or what influenced his work in the course, Michael talked about the course instructor, his cousin who couldn't find a roommate, and YouTube. The instructor's attitude made a strong impression on Michael, "There's never a wrong idea with [the instructor]." He described how the instructor was open to any idea and if it wasn't "exactly right" he would just try to "shift" it a little. When the instructor heard new ideas from students he would pause, think, and say something like, "Wow, I honestly just never thought of it like that." Michael said his cousin, the Adobe XD online forum, and "those YouTube channels" influenced his project work but reserved his highest praise for the course instructor, "He never makes you feel like you're wrong, which I really like."

Julie. Julie was a 19-year-old sophomore communication sciences and disorders major who designed a mobile app to help homeowners get into gardening. When asked, "Why gardening?" she talked about her childhood memories of gardening with her mom. "When I was a little kid, like I loved gardening with my mom and we always had a flower bed in front of our yard." Gardening was a family tradition because Julie's grandmother was the "expert" gardener. When asked how the idea came to her, she said it took some time. One day while Julie walked down a street in her neighborhood, she wondered what her idea would be. She recounted the instructor's advice, "Just think of things in your daily life that um, may not necessarily be a problem, but that could be improved." The street happened to be in a historic district, she noticed the perfectly landscaped, beautiful yards and thought, "How do they get it to look like that? Why can't everyone's yard look like that?" Then she remembered her grandmother using pen and paper to plan her gardens and how many factors there were to consider. Julie had other potential project ideas, and it was a couple of weeks into the course before she finally decided on the gardening app. However, "once it hit, it felt like it grew like crazy."

When asked how she felt about having extended time to think of a project idea, she said having the extra "wiggle room" kept her from being "stuck" on a project she wasn't as passionate about. Julie wanted to help people have the "therapeutic" experience of "digging and planting" and "being in the garden." She liked having time to "mess around" and entertain different ideas. During this time, childhood memories helped her visualize the app's design. For example, when she and her brothers were younger, they played *Webkinz*, a virtual world simulation. She remembered the gardening parts of the game and used them for design inspiration, "It was kinda like that, but more realistic and more based off of your own yard." Julie had a lot of ideas and choosing among them posed a problem for her, but this cluster of ideas also seemed to engage her strongly.

When asked about the degree of freedom she had in her project work, she said this course was different from her previous school experience. "Coming from a background of like having very structured, like obviously like all the way up through like K through 12, is like very structured. Like everything you do is like on a timeline." She did want extra guidance for the more complicated software options and wished they were introduced earlier because some of the software took "quite a bit of time to adjust to" and "playing around with it" took time. She appreciated the guidance of the in-class activities where students rotated and regularly shared the tools they were using and their project ideas.

The three main challenges Julie experienced in her work were learning to use design software, learning to focus her ideas, and the worry that she would not be able to complete an acceptable project. Her biggest worry came right at the beginning of the course because she had never needed to "come up with some new innovative thing." This kind of project work was a new experience for her. She was not sure what to do or if she could do it—whatever it was. Julie said, "It can be pretty stressful like coming into a situation like this class where, um, you have like pretty much free reign." Once she decided on a gardening app, she worried that she did not know enough about gardening and was not sure how or where she would find all that information. However, she soon realized, "the more you look into it, the more resources…are like available to you I guess." After choosing a project topic that exited her she wondered if she could do it, and that is when the community within the course helped.

Prototyping and interacting with her peers helped Julie get past the challenges. Paper prototyping allowed her to focus on design ideas without needing to learn to use design software simultaneously. She thought some of her classmates could 'jump right in" to using prototyping software, but Julie said the hand sketches were necessary for her design process. "That kind of like made it more real for me to be like, okay, my ideas are actually tangible, like this is actually something you can click through and, umm, see." She described how drawing her app idea on paper forced her to think about interface elements she would otherwise have glossed over, such as the navigation elements for each screen. As she moved from paper to digital prototypes, Julie found the Marvel App software appealing because it was easy to bring her hand sketches into the software and add interactivity. She also used the more complicated Adobe software but wished it was introduced earlier in the course because its learning curve was steep and time-consuming.

Julie understood online software tutorials were available but preferred to jump right into it. "The way I like to do is just kind of play around with it, like pick something that's not so serious, like, and then play around…" She also enjoyed the class time when she was learning from classmates who were already familiar with the software. "I'm pretty lucky I have a classmate that's like really fluid and like what he does…having a peer to be like, okay, like this would make it easier if you did this…" Presenting ideas also helped her learning process.

> When I presented my idea in class, I was pretty like I was overwhelmed with the feedback…I could see … different people using [her app] and that made me feel good because then I felt like this is something that could be real. Like it's not just a class project…having that, um, support makes it feel like what you're doing isn't just for a grade.

She said these in-class prototyping activities made her feel more passionate about her ideas and work in the class.

This passion resulted in Julie having many ideas, which became overwhelming, but this problem was familiar to her. She had “always been that person” who went above and beyond requirements. When asked to make a single slide, she would “add a million slides” and go “way over the word limit.” She knew it was a problem, “For me, …that has definitely been my number one challenge.” When Julie’s ideas for the app overwhelmed and stalled her design process, she called her grandmother, who advised her to go back to the basics. She saw her grandmother as part of the target audience and said, “I guess [my] like target audience like has definitely been my, my biggest help.”

Peer and instructor feedback also helped her design process. She explained, “the environment of our classroom is much different than any other classroom I'm in.” She appreciated being able to “bounce ideas off each other” and how it helped support her design process. She laughed as she recalled an unusual project idea from one of her classmates. “You know, and if you had said that in my hearing science class, people would look at you like—you're crazy! [laughs] But I love it.”

Near the end of the interview, Julie talked about what design meant to her. She said design was “creating something” but also felt “like it's this changing idea.” The design was not the app. “Like it's gardening, it's something like real, it's something tangible and then like watching it be able to grow, and the process behind it has made me appreciate everything more.” She felt that design “makes people feel more empowered” and seeing the result of her work made “the whole thing worthwhile.” Julie summarized and said design is this “ever-changing thing that [can] like completely like be changed at any point in time…the whole point of it is to like redefine itself and like redefine everything around you.”

Scott. Scott was a 19-year-old sophomore accounting major. He designed a mobile app to help make finding and paying for parking easier. When asked how he got his project idea Scott said, “I hate the parking here. It's frustrating.” He didn’t like searching for parking spots and said the problem was the same in his hometown. His idea involved a subscription service to take the hassle out of payment, a GPS to locate available parking spots based on the user's location, and a feature to remember where users' parked. "It's like an all-in-one parking app," he said. Scott explained he had several app ideas, all of which involved parking, so he combined them all into a single app.

When I asked Scott about the challenges in his project work, he told me he was "not a big tech guy, ah, my major has nothing to do with like technology." All the design software was new to him, and he took his cues from the instructor's recommendations in class, where the basics of design software were introduced. He said he "used YouTube all the time" and was in the process of learning to use the software. I asked Scott if he had a system for learning new software. "I mean, I [laughs] a lot of struggle a lot of trial and error..." At first, he thought creating a functional prototype would be complicated but was surprised how simple it could be to design an interactive prototype with this new software that was "good to learn."

Scott began by claiming he used Adobe XD to make his prototype but was not able to elaborate his use of it in any detail. He was more familiar with the Marvel App design software, which was easier to learn, but he thought Adobe XD was "better."

> I feel like it's got more. It's, it's a lil...it looks better. First of all, it's got a lot more capabilities...with the Marvel you kinda just take a picture of something you draw and you can kind of get a rough idea for what it is, but it doesn't look very professional. It doesn't look very clean. And with the Adobe, it's, I mean you're using a computer to do it so it's a lot more precise and it looks a lot better.

For Scott, it was important that his prototype looked "clean." When asked what he thought about sketching with pencil and paper, he said sketching was "definitely helpful." We explained that he was "not an artist, so it didn't look great," but getting ideas on paper helped him "get a better grasp" of what he was trying to do and made it easier to show other people. Although the easier to learn Marvel App software did not produce the look that could be achieved with Adobe XD, it allowed Scott to import his sketches as the basis of an interactive prototype. He liked being able to see his work “like a phone screen and how it would look in your hand” and thought it was useful and good for his process.

Once Scott drew his interface design, he didn’t make changes to it until the instructor introduced a prototyping activity in class. He said when the activity “made us go through and pretend like we were actually using it, I kind of realized a lot of things that it was missing. So I would add in extra screens…” After the activity, he realized the changes he made were hard to visualize when they were just thoughts, and that a physical prototype helped him have new design ideas.

When Scott was asked to talk about the level of freedom he had in his project work, he said he “definitely” liked being able to choose his own project idea and said this choice helped motivate project work. Nonetheless, he had trouble clarifying the details of his final project.

> But I will say as someone who is an accounting major, I like a lot of structure… I do think that some structure is helpful along the way, 'cause sometimes I found myself kinda wondering like what the end goal was until recently… But sometimes for me that is kinda, it's almost like less motivation if you don't know what you're trying to get to in some ways. So I feel like there are some ways that like structure could be an improvement on it, if that makes sense.

Although Scott eventually understood expectations for his project, he said that for a while, he had been unsure if he was supposed to “take it further” than the digital prototype. Scott thought he needed to program a functional app, even though the message that the final project was not expected to be functional was reiterated throughout the course in class and in the course materials. Scott wished he understood earlier that he would be using design software, and not only paper prototypes, to deliver his final project.

> I feel like it would be nice to know that like toward that at the end you're trying to get to make a digital prototype that's like on a computer, not something you've

> drawn so you know where you're trying to go and you can kind of budget your time a little bit better.

It seemed like Scott wished his prototype looked more like an actual app and that he used more advanced prototyping software (e.g., Adobe XD.)

He said the instructor helped him narrow down his project ideas and make the decision to consolidate his various parking app ideas into one. Scott had gotten to know his classmates and said the in-class prototyping activities helped him figure out what to “add or take away.” He talked to his friends outside of the course about his project and got ideas from them as well. When Scott was asked to talk about what design meant to him, he said it involved making something better and that it was also “pretty open-ended.” He concluded, “Maybe solving a problem is the best. I think if you're going to design something, it should have a use, and it should solve a problem [laughs].”

This interview lasted only 15 minutes, and it was unclear why it was so much shorter than the others. The course instructor administered a creativity beliefs survey (O’Connor, Nemeth, & Akutsu, 2013) to students during the beginning of this course (the same day I administered my first surveys), and Scott’s score was the lowest of all. The survey measured how students rated their creative malleability (i.e., openness to the idea they could increase their levels of creativity.) That data is not a part of this study, and the anecdote is only mentioned because of the unusually short interview when compared with the other interviewees.

Another possibility for the briefness of the interview was that Scott was a little uncomfortable when he was unable to provide any detail of Adobe XD after having claimed to be using it. I tried to be entirely non-judgmental and even laughed along with him, but my hunch is that Scott got mistakenly trapped by wanting to please the interviewer and in so doing, boxed himself into an uncomfortable situation. This would mean the interview data might be subject to some form of response bias, such as *satisficing* or *social desirability response bias* (Holbrook, Green, & Krosnick, 2003).

Alex. Alex was a 20-year-old junior finance major. He designed a mobile app to help high school seniors with their college search process. He said that when he invested "a lot of time and effort" into something, he wanted it to be "meaningful." When he considered project ideas, he thought the poor decisions his cousin made when choosing between colleges. Unaware of the practical and affordable options available to him, Alex's cousin made choices that resulted in a difficult and overwhelming financial burden for him and his family.

> My cousin went through a hard time. I was overwhelmed by like all that. So then that kinda was like fuel for me...that okay...I went through that, like my family went through that, but maybe I can help like...it easier, make it easy on someone else's family.

Surprised the cousin wasn't aware of less-expensive alternatives, I asked Alex if his cousin was advised in high school about his range of available options. Alex replied, "Oh, definitely not." I pressed, "No??" Alex explained, "No. It's like... not at all", and added that neither he nor anyone he knew received advice when searching for colleges. He paused to clarify that there *was* advice, but it was "minimal," and did not include making students aware of the many options available to them outside of the commonly-known "standard" institutions.

It was only two years and $10,000.00 later when his cousin realized he could have chosen a two-year college close to home, commuted, and eventually transferred to graduate from a larger, more expensive institution. Alex said the lack of support, combined with the excitement and stress of selecting a college, was to blame for his cousin's trouble. Alex wanted to design an app that would help prospective undergraduates make better financial choices when deciding where they would go to college. He said, "I just feel like the users would get a lot of good use out of it, and it'd be very practical."

When asked to talk about challenges that stood out for him in his project work, Alex explained the “biggest struggle” in his design process was deciding how to limit the scope of the app’s functionality. He said he was feeling overwhelmed earlier that day and was talking with the instructor about his concern that he could not include all his ideas in the prototype, which was due later in the week. He said the initial idea was an “all-in-one” app that guided the whole process for college search and selection, “But um, I will say that was a tad bit ambitious because I underestimated how much really does go into the selection process.”

To limit the app, Alex first performed a calculus on the problem and sliced it into smaller parts to make it more manageable. As he analyzed the college search process, he realized the initial part of the search was the real problem. He explained, “After you've got it narrowed down, I really do think that's like the majority of the stress is relieved, and that was what I was trying to do.” His breakthrough idea was to help users find a few good options, at which point they would do the rest. Alex reframed the problem from (a) the entire search process to the (b) first phase of the search process. With this *frame creation* (Dorst, 2015), Alex was able to create a (c) working solution. As he said, “After that, it became super easy 'cause it's like, what? Three sites you have to go on? Like two or three phone calls?”

Alex explained how his design benefited from the prototyping and feedback activities in class, “It's funny because, none of the things that, the feedback that [was given] I actually used, but it helped me think of other things.” He used the problems peers pointed out with their feedback as starting points for redesign, but not necessarily their specific recommendations. Alex said the feedback was indispensable, “You have to…value the opinion, like, of your peers 'cause like they're not going to be biased to you, they just gonna tell you straight up, so...[it] was very, very good to share.” He appreciated how easy it was for designers to not see design flaws in their own work that were easily seen by others, “Your mind's kind of trained to overlook minor details…that you may be lacking in your project. So to get that outside perspective, uh, it's very nice."

Alex liked the combination of hand sketching and the Marvel App prototyping software. He said the option to "draw like your different screens and like how you want it to all mesh together—I think is something that's super helpful." I wondered aloud what he thought of the other software some students used to build prototypes. He understood some people found presets and templates offered by other design software helpful, but "when you want something to really look like your own… there's really no preset design out there that's really going to encompass what you truly want it to look like."

Alex wanted his prototype to look like his own. He spent extended time designing a logo for it and enjoyed hand sketching it. He showed his drawings to me, and the logo was clever and well-executed. I asked if he planned to recreate it digitally, but he was more interested in using his hands than software for this. And anyway, he had a friend he had who was a graphic designer that might help him later. Just as with the screen designs, Alex preferred hand sketching and said since he was doing "something [he] wanted," he also wanted to spend the "time and effort to make it look good." He told me he reworked the logo at least 50 times. "I'm pretty proud of it," he said.

Alex approved of the level of freedom involved in his project work. He "loved [that] from the beginning because...everyone has ah like different stories, different passions and the ability to uh, I guess not be corralled in." He explained how his classmates were all working on projects that were meaningful to them, and what was meaningful for one student did not necessarily work for another.

> I want to do my own thing. So like the ability to just kinda, ah, and I think that goes with like the whole premise of the class, like design thinking, being creative, like what really, uh, like everyone having their unique, like, perspective

> and stuff I think is ah...that just ties nicely...having that, ah, liberty to choose, like, what you want to do as far as the topic of the project.

Alex wished he had more guidance in finding the right design software because he went through a process of downloading different applications only to realize many of them overpromised and underdelivered. We observed how the internet is littered with false marketing claims, and he described his experience of selecting and rejecting possible software tools, “You get to do like two things, and then your trial ends. So I'm just like, oh, that's, that's not what it was advertised as this, that's not cool.”

When asked what design meant to him, Alex said design created something of value and was often tied to emotion, like the feelings he had for his cousin or his younger sister, who would soon be searching for colleges. “You can have different ideas come from different people, but the origin and the 'why' is always going to be different. And I think that's what fuels ah, like creativity, like, to begin with.” For Alex, the creator’s motivation was a distinguishing characteristic of creative design. He continued and described how his experience within the group of students informed his opinion.

> Just getting like a different perspective and realizing, uh, that everybody's got like great ideas, and you shouldn't let anyone like shut you down or whatever. It's like it was very important, and something [that] is much more applicable than just this class. Like, that goes for like, it's like a life lesson...you got to believe in yourself, you know.

At the end of the interview, Alex added he wasn’t expecting this kind of course, but it was a “pleasant surprise” because he expected it would be “super, super heavily like technical.”

Interview Themes

Table 38 shows the ten most assigned codes across all interview text. The frequency of each code is shown alongside its percentage of coverage across the group. The related statistics from the journal data are included for comparison.

Table 38

Interview Code Rankings

Code	Code category	Frequency: interviews (% interviewees referencing code)	Frequency: journals (% participants referencing code)
Community	action	62 (100%)	42 (72%)
Tool exploration	action	35 (100%)	81 (92%)
Feedback seeking	action	33 (100%)	36 (72%)
Prototyping	action	26 (100%)	73 (92%)
Exploring project options	action	23 (80%)	63 (96%)
Empathy - human-centeredness	affect	22 (80%)	52 (100%)
Motivation	affect	19 (60%)	18 (44%)
Problem finding	action	14 (100%)	33 (80%)
Playful attitude fun/excitement	affect	11 (100%)	11 (32%)
Locating and using resources	action	10 (80%)	17 (48%)

Note: Codes omitted from rankings: Contradictions, Subject, Outcome, Existing activity system, Division of labor, Emerging-new activity system

The interview data did not contradict the journal data and generally corroborated findings from the journals. Both tool exploration and prototyping were prominent in the interviews and journals, but the main difference between the interviews and journals was in how the interviews amplified the social aspect of participants' creative design process. The code rankings show community as the most assigned code across the interviews by a wide margin, and they had 100% coverage across interviewees. The community code still ranked highly in the journal data, just not to this extent.

All interviewees talked about the social aspects of their design process, which included their individual social circles (e.g., family, friends, supportive social media) and the classroom community (i.e., peers and the instructor.) The social aspect was present throughout participant's creative design process, from the early stages when participants' drew inspiration for project ideas from their personal communities, to the tool use and prototyping that characterized much of participants' activity, and to the final reflective stage when participants' spoke of how their peers and the course instructor influenced their design work in the course.

Prototyping and feedback arguably would not have existed without the social aspect of the community, which supported the development of participants' creative design ability. Social dimensions of prototyping included project feedback between peers and individual presentations of project ideas and tool use experience. All interviewees emphasized the helpfulness of their interactions with the course instructor and described the instructor's openness to creative ideas and receptiveness to students' tentative expression possibilities for project development. The instructor apparently was able to create and maintain a tone of psychological safety that was conducive to creative behaviors. In all, the interview data emphasized the community both in and out of the classroom as positive factors that influenced their creative design work.

The interviews also emphasized participant motivation and how it was established and sustained. When the interviewees talked about choosing project ideas, it was clear they cared about their projects. Their project ideas came from their past social experiences that usually involved family and sometimes childhood memories. Consistently, interviewees emphasized their engagement with choosing projects, and this feeling also extended to tool selection, learning, and use. When interviewees described challenges or frustrations around project design decisions or using design tools, they usually talked about their feelings of accomplishment, pride, and confidence. Most interviewees were explicit that the personally meaningful projects helped them feel motivated in their project work. Others mentioned how the instructor and peer feedback around prototyping activities helped motivate them for project work. It appeared that freedom of choice helped establish participant motivation for project work, and social interaction inside and out of the course helped to sustain it.

Themes other than community and motivation were found, and Figure 42 shows the combination of the six main themes that emerged from the interview data. Although each theme was distinct, none were mutually exclusive. These themes tended to co-occur, intertwine, and entangle throughout the participants' project work.

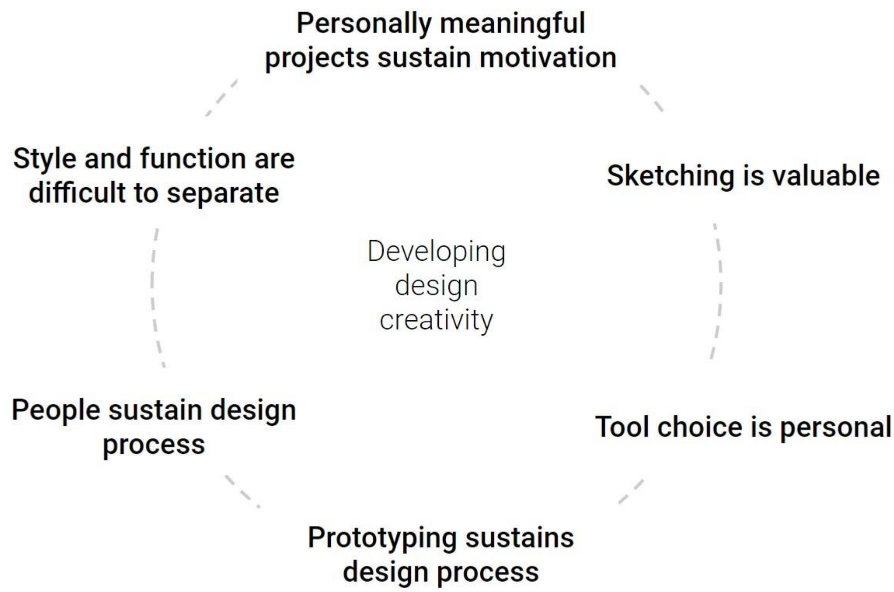

Figure 42. Themes found in interview data

During the interviews, the participants were prompted to talk about challenges they faced in their project work, the tools they used, influences on their work, how they came up with project ideas, and how they felt about their freedom in their project work. The six themes that emerged from this study are listed below and followed by brief descriptions.

1. Personal project choice led to problem-finding, divergent thinking, human-centered design, and ambiguity tolerance. Projects that held personal meaning appeared to sustain student motivation for project work across the length of the semester.
2. Prototyping activities sustained design process (e.g., making the prototype, presenting the prototype, feedback from the prototype.)
3. People, in and outside of class, sustained the design process.
4. Tool choice was personal.

5. Sketching was valuable.
6. Form and function were unified and difficult to separate.

Personal project choice influenced participants' intrinsic motivation to sustain project work throughout the course. Additionally, the requirement that participants choose their project ideas invoked the need to engage with problem-finding, divergent thinking, human-centered design, and ambiguity tolerance. Projects held personal meaning for participants and served to connect their prior experiences with the development of creative design abilities.

Prototyping actions served as a hub to unify other design actions such as divergent/convergent thinking, presentation of design ideas. Creating prototypes helped participants clarify their design ideas at the individual level and were central to their presentation of design ideas and feedback actions. Prototyping facilitated classroom interactions and helped to build a classroom culture that supported the development of creative design ability. The culture included feelings of psychological safety through a classroom culture that was supportive and accepting of participant creativity. Prototyping also facilitated participants' tool learning. Overall, prototyping helped to build and sustain a classroom culture appropriate to design work and led to participants sharing their design ideas both in and out of the classroom.

The classroom community and the extended community that each participant brought into their design process sustained the design process. There was no evidence that any of them worked primarily worked on their own. Although participants did spend much time doing solo work on their projects, the interactions with people around project work seemed to most influence the development of design ability.

There was no agreed-upon tool or set of tools that participants used for their design work. Each of them expressed strong preferences for the toolsets they chose to use. Tool choice seemed to be related to personal preference and ability level with design software. Prototyping activities instigated tool selection and tool learning involved peer-to-peer interactions and the internet as a resource. Some participants seemed to believe they needed to use what they perceived as more advanced or professional prototyping software, which seemed to lead to frustrations for several of them.

All participants reported that sketching was invaluable to the development of their design process, and they all reported enjoying the physical act of sketching as well. The one participant who did not use physical sketching used a digital tablet to sketch and made digital sketches on a near-daily basis—for some, sketching led to feelings of ownership of project work. Sketching often served to bridge design and technology, as when participants' imported their hand sketches into prototyping software and created interactive prototypes for more peer and instructor feedback.

Although not a majorly predominant theme, the difficulty in separating aesthetics and style from other design elements was difficult for some participants, this happened for a minority of them, but it did seem to stall the progress of the design work. These participants fixated on the style of their prototypes, and it seemed as if the way the prototypes looked defined their perceptions of the quality and value of the prototypes. Low-fidelity prototypes were associated with dissatisfaction and some frustration, especially as these participants approached the end of their project work.

Design Thinking Traits Survey Data

The design thinking traits survey was administered during weeks two and 15 of the course. The response rate was 76%, with 22 responses obtained from the 28 total students in the course. There were 28 students enrolled in the course. Three students did not participate in the study, and three participants missed either the pre or the post-survey. Therefore, 22 participants completed this survey.

The survey consisted of nine statement items with which respondents were asked to indicate their agreement using a five-point Likert response scale. The nine survey items correspond with five underlying traits characteristic of design thinking behavior, and these items were developed through a process of literature review, focus group testing, and exploratory factor analyses (Blizzard et al., 2015). This survey instrument was used as a pre and post measure for changes in students' design characteristics during the semester. Additionally, the five underlying traits associated with design thinking were integrated with the coding scheme developed and used in this study to assist in the analysis of textual data.

Participant scores on both the pre-test and the post-test were high. An independent samples t-test assuming unequal variances showed a statistically significant rise from a group mean of 36.59 during the second week of the course to a group mean of 39.23 during week 15 of the course. This suggests that even though students came to the course with dispositions associated with design thinking, their course experience improved their attitudes toward it. Although the gain is not dramatic, it does not contradict and is supportive of the findings from the textual data from journals and interviews. The statistical data for the pre and post-test results are displayed in Table 39 below.

Table 39

Design Thinking Traits Pre/Post-T-Test Results

	n = 22	
t-Test: Two-Sample Assuming Unequal Variances	*Pre-test*	*Post-test*
Mean	36.59	39.23
Variance	5.02	12.85
Observations	22.00	22.00
Hypothesized Mean Difference	0.00	
df	35.00	
t Stat	-2.93	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.69	
P(T<=t) two-tail	0.01	
t Critical two-tail	2.03	

Design Thinking Survey Factors as Codes

The five underlying design thinking factors identified by (Blizzard et al., 2015) to build their survey were integrated with the coding scheme and used to analyze journal and interview data. The underlying factors measured by this survey were (a) Feedback seekers, (b) Integrative thinking, (c) Optimism, (d) Experimentalism, and (e) Collaboration. In some cases, the factors were extended with child codes. Table 40 shows this aspect of the coding scheme and how frequently these factors were referenced across and within the journal and interview data. The five factors are set in bold type.

Table 40

References to Five Design Thinking Factors

Code	All Journals	Journal I	Journal II	Journal III	Journal IV	Interviews
Experimentalism *(action)* - *Convergent thinking/evaluation* - *Divergent thinking/ideation* - *Problem finding* - *Prototyping* - *Questioning*	128	32	37	37	22	60
Feedback seeking *(action)* - *Empathy/human-centeredness*	84	31	9	27	17	55
Optimism *(affect)* - *Creative agency*	33	4	1	6	22	9
Collaboration *(action)*	7	1	0	2	4	9
Integrative thinking *(action)* - *Framing*	3	0	1	0	2	2

These numbers suggest participant development and outcomes were primarily characterized by experimental behaviors such as prototyping and its related feedback seeking behavior. Optimism emerged toward the end of the course, and the increase in references with journal IV could be because students were asked to discuss the meaning of their course experience, and many of them wrote about increased feelings of confidence and appreciation of creativity both within themselves and others. Although students did interact with each other for in-class project feedback, tool learning, and prototyping, they each worked on individual projects, which explains the low and potentially misleading numbers for collaboration. In a sense, participants "collaborated" and shared with each other to improve their individual products. Nonetheless, individuals ultimately worked on their individual projects (albeit often in a collective manner), and therefore the code for collaboration was infrequently assigned, and the codes for feedback seeking or empathy/human-centeredness were often assigned. Overall, this coded data showed that experimentalism, feedback seeking, and optimism characterized participants' activity in the course. According to the code rankings, integrative thinking was not explicitly mentioned in participant journals and interviews, but it is impossible to conclude participants engaged in little or no "big picture" or systems thinking during their work.

Summary of Findings

The data suggested participants' creative design abilities were shaped through object-oriented activity (i.e., design and delivery of final projects) characterized by a clustered sequence of interlocked actions and affective states that evolved across the duration of the study. The extended time participants' spent engaged with project work seemed to support deeper, meaningful learning (Pellegrino & Hilton, 2012). The participants' initial motivation for project work appeared to be driven by their choices of personally meaningful projects. After several weeks, the individual presentation of project ideas in class appeared to me a milestone marker for the establishment of a supportive course community. As participants next identified and learned to use design tools, the combination of autonomy and a supportive community appeared to support participant development. The freedom to choose and drop design tools and the presentation of tool experiences with the rest of the class supported motivation and development. This trend continued with prototyping activities, which seemed to have supported the growth of the community, of participants' engagement with the course, of their design abilities, and their creative agency.

A key quality of the community was the psychological tone of safety regarding creative expression that the instructor modeled and sustained throughout the course. According to the interview data, the instructor's tone with participants involved an openness to and respect for their ideas. It is a reasonable assumption that the instructors' modeling of interest and respect for participant ideas influenced how participants viewed their project work and that of their peers. This may have supported the use of empathy and human centeredness found in relation to project topic identification and design choices based on peer feedback. The way in which these attitudes influenced the use of design methods may have, in turn, supported the development of creative agency. The prevailing attitudes in the community may have also helped to sustain the strong motivation and persistence found throughout participants' course work. The high degree of learner autonomy may have also supported participants' motivation, and the freedom to make critical design choices seems to have supported the reported outcomes of creative agency.

One apparent trend was how participants expanded their design methodologies from individual to collective orientations through the actions of prototyping and feedback within the course's community. Figure 43 shows this progression as a series of activity system states, each informed by their related journal entries. A ratio is used to represent an integration of the most prominent actions and affective states found in participant activity. The dark circles indicate the most active components of the system, and the light circles indicate a lesser emphasis, as suggested by the journal and interview data.

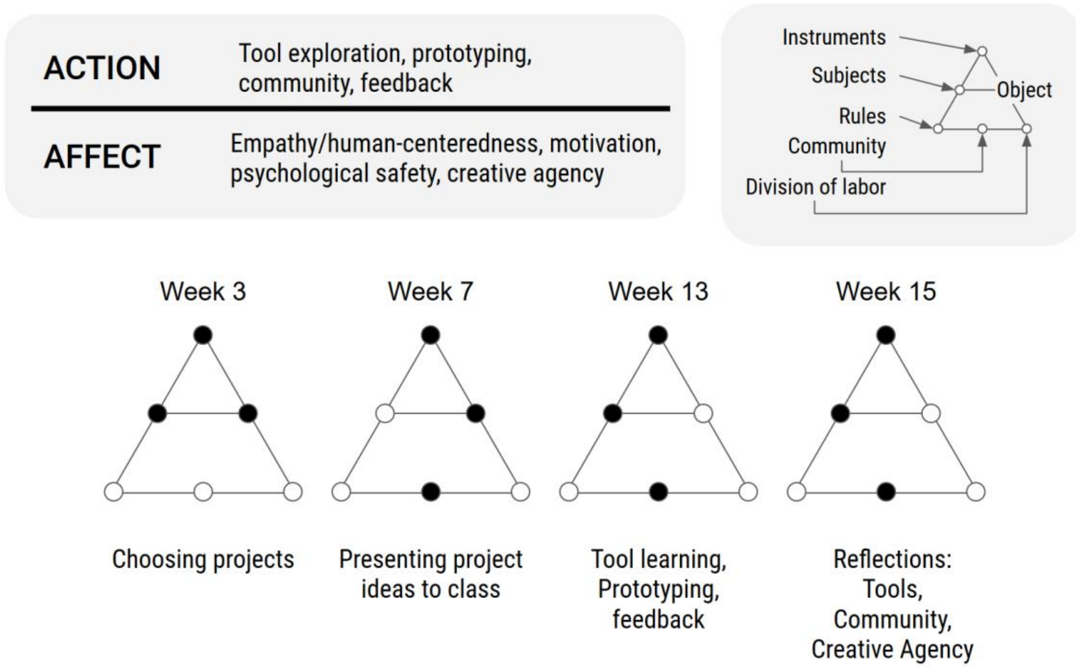

Figure 43. Actions, affect, activity system sequence

The "instruments" node of the system was consistently active. This made sense because the participants' main objective was the construction of final projects. Instruments included externally oriented design tools like prototyping and software and internally oriented tools like design methodologies. The course system began by activating the upper portion of the triangle as participants focused on resolving the object of the system—what their projects would be (week three.) The community node of the system emerged when participants first presented their project ideas in class. The focus of activity appeared to shift away from the individual and toward the community (week seven.) From this point on, the community appeared to grow in influence as it became a collective hub of activity that supported a variety of factors such as tool learning, prototyping, and feedback (week 13.) At the end of the course cycle, participants' most reported outcomes were increased confidence in tool use and new feelings of creative agency, which extended to a new appreciation for the creativity in others, especially as it related to receiving feedback and improving design ideas (week 15.)

CHAPTER 5

DISCUSSION

High-Level Overview

It appears that high levels of learner autonomy, project-work within a supportive community, and extended time for practice led to outcomes of creative agency and the use of the course community as a collective design tool. A cluster of five interrelated factors, their dimensions, and their changes throughout the course stood out as the main contextual factors that shaped participants' creative design ability. These factors were (a) tool exploration, (b) prototyping, (c) community, (d) motivation, and (e) creative agency. The course's community emerged as a collective hub for activity that was shaped and amplified by the other factors. Very importantly, the course instructor modeled an overall tone of psychological safety supportive of creative expression and provided practical guidance for the use of creative design methods. Learner autonomy facilitated participants' motivation and engagement with personally meaningful design choices. This dynamic and entangled cluster of factors were the most frequently mentioned actions and affect throughout the journal and interview data, which suggests them as factors that can accurately model the course as an activity system.

A reason why *these* five factors received the highest amount of references is that they frequently overlapped with each other. In other words, the most referenced codes were also the most interconnected. It is difficult to talk about one factor without mentioning the others, and therefore they are discussed as a cluster before their separate discussions.

A higher-level perspective across the course activity system reveals three general categories that organize the five factors that emerged from this study. The three categories were

(a) actions (e.g., behavior, cognition), (b) affect (e.g., emotions), and (c) social (e.g., environmental.) Actions included cognitive behaviors that were not directly observable, such as problem finding and framing, along with more directly observable behaviors such as prototyping and tool exploration. Affect included participants' feelings, such as motivation and creative agency. The social category included the courses' community and its dimensions. Collapsing activity to fewer than these three categories would impair meaningful discussion of it.

The triangular mechanic of activity was unsurprising but did serve to contextualize this study's results with the related theory about human development. Literature spanning the domains of philosophy, educational psychology, creativity, and design offer longstanding theorizations of human learning and development as a triadic cluster of actions, affect, and the environment. For strategic exploration, it is useful to frame existing theoretical perspectives around the phenomena of interest, so a brief overview of relevant preexisting theory precedes the discussion of the signature five factors found in this system.

Precedents in the literature. The dynamic and reciprocal aspect of learning was described in Hegel's (1991) philosophical concept of the dialectic, in Vygotsky's (1978) triangular mechanic of mediated activity, in activity theory's elaboration of this triangular mechanic (Engeström, 2014; Leont'ev, 1972), and in Bandura's (1978) *reciprocal determinism*. A need to approach creativity using a systems or eclectic perspective has been emphasized by Csikszentmihalyi (1988) and Runco (2007), respectively. Writing from the design research domain, Rauth et al. (2010) held that, "Design creativity requires various techniques, methods and conditions" (p. 1), which implies a parallel need for varied research methods. Finally, since the participants engaged with the practical activity of building projects within the course's milieu, there is close alignment with *constructionism*, as "The construction of knowledge [occurs] in the context of building personally meaningful projects" (Kafai & Resnick, 1996, p.1). Thus, the findings for this study generally align with earlier theory and are framed by the epistemological perspective that learning and development involve interactions between actions, affect, and the sociocultural-historical context of human activity.

Activity cycles and a five-factor cluster of activity. Figure 44 shows the organization of the most prominent course activity system data. The action, affect, and social categories might be generalized to any practical activity, but it was the codes for tool exploration, prototyping, community, motivation, and creative agency that largely described the specific nature of participants' experience in this course activity system. Of the thirty-eight codes in the coding scheme, it was these five that emerged most frequently from the journal and interview data in this study. The emphasis of the five factors does not imply that actions such as problem finding, affect such as empathy/human-centeredness, or social features such as on-campus 3D labs were unimportant, because these and many other factors were present in participants' activity. These lesser referenced factors connected with the five-factor cluster and characterized each of the five factors in much of the same way the cluster of five characterized the generalized three areas of activity represented in Figure 44. Nevertheless, when describing the activity system, these five-factors arguably do the best job.

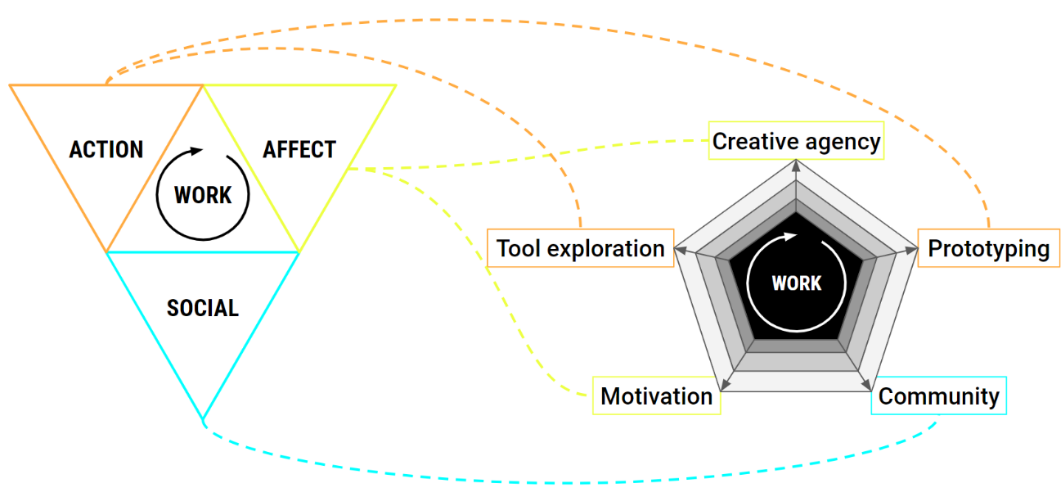

Figure 44. Categories of participant activity

It might seem obvious, but the participants' work fueled this system. Work (i.e., participants' project work) instantiated the interactions between these factors and their subsequent development. Designing and building final projects was what made the development of participants' design creativity possible. This key feature of constructionism and project-based learning focused on participants' activity and defined the course as an activity system. Without the orientation of practical activity toward final projects, these five factors would not have emerged as they did, and their related development would not have occurred in the same way, if at all. The success of this system as a learning environment depended upon the persistent effort of the participants. This need for self-directed work suggests that deficits in participant or instructor effort would pose a major barrier to the successful implementation of this course design.

The following five sections provide discussion for each of the five contextual factors. Each section begins with an orientation to the particular factor and then proposes guidelines for its facilitation. These guidelines are based on the analysis of this course activity system, the instructor's impact on participants' development, and related literature. Although the discussion stems from this study's results, my interpretation of the results and connections to related literature are used to extend the discussion with implications and proposals. It is difficult to completely avoid repetition in the sequential discussion of these five factors because they were so entangled and reciprocally determined. Care has been taken to minimize repetition without diminishing the relatedness of the five factors.

Motivation

For this study, motivation emerged as a strong, broad effect that appeared to stem from personally meaningful project choices and decisions. Meaningful tasks appeared to pull the participants into their project work, and motivation seemed dependent upon freedom of choice within a supportive course structure. Distinctions between intrinsic and extrinsic motivation remain a prominent interest in the literature and are debatable (Rheinberg & Engeser, 2018), but this study did not use the intrinsic/extrinsic lens to examine motivation.

Motivation and autonomy. Granting participants high degrees of autonomy in their project work seems to support the motivational structures found in their journal entries and interviews. A main finding from the interview data was that personally meaningful projects sustained motivation across the duration of the course. This result is in line with the recent literature concerning creativity in the workplace. Amabile and Pratt's (2016) use of diary methods revealed the relationship between progress in work and the perceived meaningfulness of that work:

> The most important discovery of this diary study is the progress principle: of all the work events that appear repeatedly on days of people's most positive subjective experiences, the single most prominent is making progress in meaningful work. The progress can be individual, team, or organizational, as long as the individual is aware of it. (p. 166)

Participants in this course used design journals to provide sequential updates on their project work. They also repeatedly presented and shared their project work and progress in class. Autonomy in project work combined with the requirement to regularly share progress with peers, and the instructor supported participants' sustained motivation.

For example, early in the course, one participant was only able to feel confident about her project idea after she presented it to the class and received feedback. Other participants wrote and spoke of the positive motivational effect of the peer and instructor feedback they received in class and how it influenced their project work. The motivation factor is a good example of reciprocal entanglement within the cluster of other factors. For example, motivation, prototyping, presentations, and the community reciprocally determined each other for the majority of participants in this study. This dynamic occurred early in the course as project topics were chosen, and throughout the course, as participants used design tools to construct, present, and receive feedback on their prototypes.

Participants in this study were granted autonomy throughout their project work across the semester. From project topics, to design tools, and to delivery formats, participants made design choices across a range of design areas that linked with their interests. The positive link between motivation and autonomy is documented in the literature as a strength of project-based learning environments (Condliffe, 2016; Thomas, 2000). In the creativity literature, Feist (1998) found a positive correlation between autonomy and creativity.

Autonomy and ambiguity. Positive motivational effects are often reported as a result of project-based learning research (Condliffe, 2017; Kokotsaki et al., 2016; Ruikar & Demian, 2013), and strong motivational orientations appear to have been a factor in creating authentic states of ambiguity that aligned with individual participant characteristics and interests. In this way, the unique project choices made by each participant led to the unique sets of ambiguities, contradictions, and challenges that shaped their development. Without this level of autonomy (e.g., absence of direct instruction), participants would not have had opportunities to experience ambiguous states characteristic of design problems and, therefore—no opportunity to make their own design decisions.

The productive relationship between ambiguity and learning is not a new idea. Dewey (1910) described ambiguity as part of the *uncertainty*, *perplexity*, *hesitation*, and *doubt* of the reflective aspect of thinking. This kind of ambiguity set conditions for a relaxed attentiveness that may have allowed participants to freely dwell in a set of design spaces, problems, and solutions. This kind of free, reflective engagement may rest on the cusp of illumination of creative ideas. It might be one aspect of creative design that some consider to be "fun," and engaging.

> To be playful and serious at the same time is possible, and it defines the ideal mental condition. Absence of dogmatism and prejudice, presence of intellectual

> curiosity and flexibility, are manifest in the free play of the mind upon a topic. (Dewey, 1919, p. 218)

Autonomy appeared to be the key to authentic project work and the motivation to do it. With these elements in place, navigating ambiguity and making design choices was fun, and an important part of learning, according to participants.

Granting participants degrees of autonomy that illicit authentic states of uncertainty and the need to think and work through ambiguity is helpful because *reflective thinking* is a key part of the design process (Cross, 1999; Hong & Choi, 2019; Schön, 1983.) The data suggested that participants felt their efforts were meaningful because those efforts related to project topics they cared about, and the course design and instructor respected and supported those interests. It seems a reasonable claim that uncertainties and ambiguities were authentic, meaningful, and unique to each participant due to the high levels of learner autonomy participants had to reflect and then make design choices.

Ambiguity and frustration. Participants did experience frustration within their project work, but by the end of the course, they also reported feelings of accomplishment, optimism, and creative agency. When directly asked about feelings of frustration, the five interviewees acknowledged their moments of frustration with project work and also unanimously emphasized how much they appreciated being given a choice in their course work. Journal data suggested much the same—one of the more challenging yet rewarding aspects of the course, according to the participants involved the ambiguity of project work and the authenticity it entailed. Therefore, motivation was established by high learner autonomy, which in turn led to ambiguities within the design process that significantly challenged or frustrated participants—and resulted in some of the most significant developments in creative design ability. It appeared that some degree of contradiction in project work roughly equated to meaningful challenges and important developmental gains.

Motivation and psychological safety. In addition to the connection between motivation, autonomy, ambiguity, frustration, and meaningful challenges, the tone of *psychological safety* (Baer & Frese, 2003; Kahn, 1990; Rogers, 1954, 1958) modeled and sustained by the course instructor appeared to provide critical support and encouragement for participants' motivation to successfully manage and work through the ambiguity and challenges of project work. Several participants emphasized their appreciation of a learning environment where it was okay to have different or unusual ideas, and when they realized this was very truly the case, it seems they were more motivated to engage with creative work and to take their own ideas more seriously.

Motivation and transformational agency. Sannino, Engeström, and Lemos' (2016) examples of formative intervention research is especially analogous to a course such as the focus on this study because the outcomes of both depend upon granting participants high degrees of autonomy, facilitating contradictions that confront the participants, and supporting the development of *transformative agency* that involves "breaking away from the given frame of action and taking the initiative to transform it" (p. 603). This transformation involves reconstructions of concepts and new realizations of the interconnectedness of knowledge, or as Engeström (2014) suggests, "The systemic nature of the genuine concept is essentially temporal, historical, and developmental" (p. 192). Ilyenkov's (1982) description of transformation is also helpful, as when he describes the transformation of "'a class in itself' into a 'class for itself'" (p. 131). This type of formative intervention research might be used to inform design iterations of courses or community outreach programs where participants take ownership and control of the design of the course/intervention itself.

Proposal 1. *Evidence suggests that motivation emerges as a support for development when learners are granted the autonomy to make design choices to resolve ambiguities within their design process. Support should be provided for learner autonomy within ambiguity so that students have opportunities to make meaningful design choices.*

Guidelines. Motivation is a perennial topic of interest for those interested how people learn and develop (Amabile, 1988; 2019; Ames, 1992; Blumenfeld et al., 1991; Deci & Ryan, 1987; Dickinson, 1995; Dweck, 2017; Eccles & Wigfield, 2002; Heckhausen & Heckhausen, 2018; Lazowski & Hulleman, 2016; Malone, 1981; Stefanou et al., 2013). It is possible to be overwhelmed by the breadth, depth, and debate found in the literature about motivation. Therefore, it came with some relief that by simply granting participants in this study the ability to make their own decisions within a generic and supportive framework, that motivation emerged as such strong support for participant work and development in the course activity system.

It is possible to simultaneously preserve the autonomy and ambiguity within students' work and provide instructional support, and support for motivation can be provided across the cognitive, affective, and social domains. Support within the cognitive domain might include information about creativity and design theory, creativity tools and methods, and design tools and methods. Support within the affective domain might include openness and respect for ideas, a tone of psychological safety that supports creativity, a playful approach to problems, and a mastery orientation (Ames, 1992) towards feedback and evaluation. Support within the social domain might include the modeling of creative behaviors and attitudes, observation and interactions with peers as they work through their design processes, and shared activities related to creative design such as testing, project feedback, iteration, and presentation. There are many ways to support students in their project work that do not impinge on their autonomy to make meaningful design choices.

Helping students develop by granting them autonomy within uncertain and challenging conditions is not a new idea, especially within the constructivist paradigm of learning. Although ambiguity was not specifically mentioned by Jonassen (1991) in his recommendations for the implementation of constructivist learning environments, he seems to have implied it: "Rather than attempting to map the structure of an external reality onto learners, constructivists recommend that we help them to construct their own meaningful and conceptually functional representations of the external world" (p. 11.) The overarching guideline, “let it happen” that was proposed in the last paragraph aligns with Lebow's (1993) first recommendation for the design of constructivist learning systems: “Maintain a buffer between the learner and the potentially damaging effects of instructional practices” (p. 5.) It is recommended instruction does not cross the line that leads to minimizing or dismissing the agency, or potential agency, of the student.

Students can be supported in many ways, and when it comes to creative design ability, an overarching guideline could be: *let it happen*. Runco (2007) recommended “let it happen” tactics for supporting creative behavior that included allowances for incubation and play. The phrase *let it happen*, was derived from Parnes (1967), who stated earlier, “our children receive so much ‘spoon-feeding’ in our present society in terms of how-to-do-it instructions-in school, at home, and later, at work-that most of them lack much opportunity for being creative” (Parnes, 1965, p. 92).

The knowledge and ability to create and sustain a tone of psychological safety (Baer & Frese, 2003; Kahn, 1990; Rogers, 1954, 1958) is important for supporting students’ motivation to engage with creative design work. When students make attempts to express their creative ideas, it is important for instructors to model acceptance and empathy. This communicates to students that their ideas are valid, regardless of their quality. Creative ideas often challenge existing norms, and a barrier to creative expression may emerge when creative ideas contradict instructors’ beliefs and values.

Finally, it is true that a high degree of autonomy does not work to motivate everyone positively. In this regard, the use of design constraints could be used to tune the degrees of freedom participants have in their project work. The ratio of direct intervention and autonomy might be adjusted based on developmental levels and cultural norms. For these upper-level undergraduate students, however, a high degree of choice seemed to support the development of creative design ability for *most* students. There were a few exceptions to the rule, however, and it remains a challenge to discover exactly why some students do not seem to engage with this kind of course, even while most do.

Tool Exploration and Use

Once project topics were settled, participant focus shifted to tools because they were required to use them to design and develop prototypes. The requirement established a need that led participants to explore, test, and select the tools they would use. Most were unfamiliar with prototyping software, and the use of paper prototypes helped to separate learning prototyping methods from learning to use design prototyping software. That is, if it were required to learn prototyping concepts and prototyping design software simultaneously, it might have overloaded the participants and been counterproductive. Moreover, although design tools can be highly technical and exciting (Boden, 1998; Clark & Chalmers, 1998; Lake et al., 2017), Cross (1999) noted that sketches and writing are commonly used by expert designers to engage with the reflective aspect of design. Although some participants may not have seen sketching as an advanced form of prototyping, the literature suggests this is not the case, and that sketching is often integral to experts' design process.

As it happened, several participants described the learning curve for the more "advanced" design software as one of their main challenges in course work. It was odd how these participants chose to use the more complicated software when a much simpler option was available. Why did they do this? According to survey reports, participants were evenly divided in their use of either Marvel App or Adobe XD software. Marvel App software was easy to learn, whereas Adobe XD software was not. One of the interviewees, Michael, was one of the most advanced participants in the group in terms of using design software, and he explicitly said the learning curve for Adobe XD was steep, even for him. Some participants seemed to equate the quality of their design ideas with the level of complexity inherent to the software they used. Might it be plausible that in seeing participants like Michael successfully use complex software, they were compelled beyond reason to do the same?

Both software applications provided the ability to create functional, interactive digital prototypes. Participants who were frustrated with software learning curves also believed the higher fidelity prototypes offered by Adobe XD were better than lower-fidelity prototypes. These participants fixated on the aesthetic style of the prototype and appeared to judge themselves and their work accordingly. They mostly resolved this frustration challenge in due time. Because the choice of software was entirely left to the participants, most eventually selected the software that worked best for them and their design process. They were able to manage complexity and keep their process moving forward, which sometimes involved the choice to abandon a given software application.

In most cases, frustrations with software learning ultimately linked with increased confidence for tool use. Working through challenges and frustrations surrounding tool use eventually ended in feelings of accomplishment. Some participants developed a critical take on software design tools and realized that software learning curves did not necessarily equate with design quality. This was the case when one student reflected that while the design templates offered by Adobe XD were slick and polished, they also brought a generic quality that detracted from the intended design. This is a good outcome that might lead to a more nuanced and critical approach to the selection and use of design software and the kind of insight that is earned through experience. It was important participants incorporated critical approaches to tool selection as part of their tool expertise.

What might cause participants to feel like they should use complicated software when they don’t need it? One might imagine that in a classroom environment with lots of interaction, some participants may see others, like Michael, using complicated software and feel a competitive urge to do the same. Or, they may conflate software ability with design creativity. Several participants who explored and then retreated from Adobe XD said their decision allowed them to relax and focus more on their projects. Finding and locating resources is a design thinking skill as identified by Razzouk and Shute (2012), and when learners can develop a critical and informed approach to software adoption, it can be assumed they are also developing more sophisticated design ability. After all, tool use was the fundamental skill needed to engage with interactive prototyping, which was a core action that facilitated the development of creative design ability for participants in this course.

Situating tool exploration and use within the social context of a community may also help provide learners with a more meaningful learning experience. Shaffer and Clinton (2006) suggested tools were not simply mediators of cognition but participants in it. In this way, tools were inherent to the active, messy, and sometimes frustrating process of learning. Many participants in this study learned about tools and how to use them from one another during class activities. Several mentioned the value of exploration and a playful approach to developing tool abilities. It may take time and missteps to develop confidence with tools, especially if that entails working through contradictions. It appeared that learning when not to use a tool was a valuable lesson and a move away from naïve tool use.

It seemed important that participants were given full autonomy in selecting with design tools they would use. Without this option, they don’t have the free reign to use a playful approach towards trial and error. For most participants, a balance between making hand sketches and incorporating those sketches into design software was the preferred workflow, but it took a lot of experience before this seemed to settle for some of them. One of the main findings from the interview data was that tool choice and use was personal for the participants; each had their own view and approach to tool use. The freedom to exercise this choice, as opposed to being told which tools to use, seems to have contributed to their eventual feelings of confidence regarding tool use. Tool choice was found to be highly personal, and successful outcomes of tool exploration seemed dependent on learner autonomy within tool selection and use.

Proposal 2. *Evidence suggests the free exploration and use of design tools leads to contradictions that result in meaningful development of tool expertise and confidence. High learner autonomy makes free and playful exploration possible, but periodically helping learners recontextualize and reframe their tool use may provide important support for the development of design creativity.*

Guidelines. Given that tools figured so prominently in the development of participants' creative design ability and that tool choice was personal for each of them, it seems wise to allow students the freedom to explore and select their own design tools. Also, because digital tools change so quickly, efforts to provide elaborate instruction for a single tool or a set of tools seem like planned obsolescence for any instructional design. Supporting competencies for locating and using appropriate tools and learning resources is a better strategy for supporting learning in a course of this kind. Therefore, it makes the most sense to help students learn how to discover and use tools based on their specific needs at the time, in addition to using a critical approach to tool selection and use. Requiring students to share their tool experience and progress with their peers periodically helps to expand the course community and the development of tool expertise and confidence.

Many of the success stories written by students emphasized feelings of fun and surprise within their process. This is not to suggest a free-for-all environment but a mindful approach to goals that involved playful attitudes. Dewey (1910) distinguished between play and playfulness. Play was associated with "physical exuberance" (p. 161) that could transform into a mental attitude of playfulness which could in turn "gradually pass into a work attitude" (p. 162.) Regarding learning and development, Dewey noted that playfulness was "a more important consideration than play. The former is an attitude of mind; the latter is a passing outward manifestation of this attitude" (pp. 161-162.) As students become acquainted with tools, an approach characterized by playful discovery may help students be less intimidated by the myriad of tool choices and levels of complexity each tool brings to the creative design process.

It may be good practice to help students balance time spent learning tools with time spent using them for practical design activity. Tools may be most powerful when they facilitate the design process, but they may also block the design process. For example, when students fixate and become bogged down in tool use, that may be a good time to redirect their activity in ways that help them see their design work from perspectives other than tool use—for example, human-centered, social, ethical, and environmental orientations towards design. A key principle might be that tools drive the development of ideas and project work when they are serving larger design goals, but an overly tool-centric focus can block the overall creative design process. An instructional approach that emphasizes the importance of ideas as leading tool use can help students gain more critical and mindful approaches to why they select tools and how they use them.

According to the data, tool learning led to the most challenging, frustrating, and rewarding experiences for students. It is important students be allowed to work through challenges because the challenges seemed to be tailored to individual students in ways that cannot be adequately described—these challenges are complex and likely involve a mixture of affective, cognitive, social, biological, and environmental factors that seemed to be unique to each student. Working through this complexity seemed to lead to feelings of accomplishment that were characterized by an increased personal agency and creative confidence. Still, there seems to be a law of diminishing returns that comes into effect for some students' tool experience, especially when students seemed to get stuck in their overall design process due to problems with tool use. Ideally, students will learn to use design tools to *design*, but sometimes difficulty with the tool precludes this.

One way to monitor the balance of time and energy spent learning to use a tool versus using the tool for design work is to think of the ratio between tool use and tool learning—tool use : tool learning. For example, student A spends three hours using a tool and ten hours learning it, which is a ratio of 3:10, or 0.3. Student B spends ten hours using a tool and three hours learning it, which is a ratio of 10:3, or 3.33. Ratios less than one indicate more time spent learning a tool than using for design tasks. Ratios greater than one indicate more time using a tool for design tasks and less time learning to operate the tool.

When the larger goal is to learn and move through a developmental cycle oriented toward creative design ability, it is recommended to keep the ratio of tool use to tool learning at one or above. This oversimplification of the dynamic between learning to use tools and getting work done with them could be a helpful metric for analyzing students' tool use. The concept could be explained to students so that they could self-monitor their tool learning and better gauge when they are entering the area of diminishing returns regarding tool use and their overall creative design process. The tool use ratio guideline is represented in Figure 45.

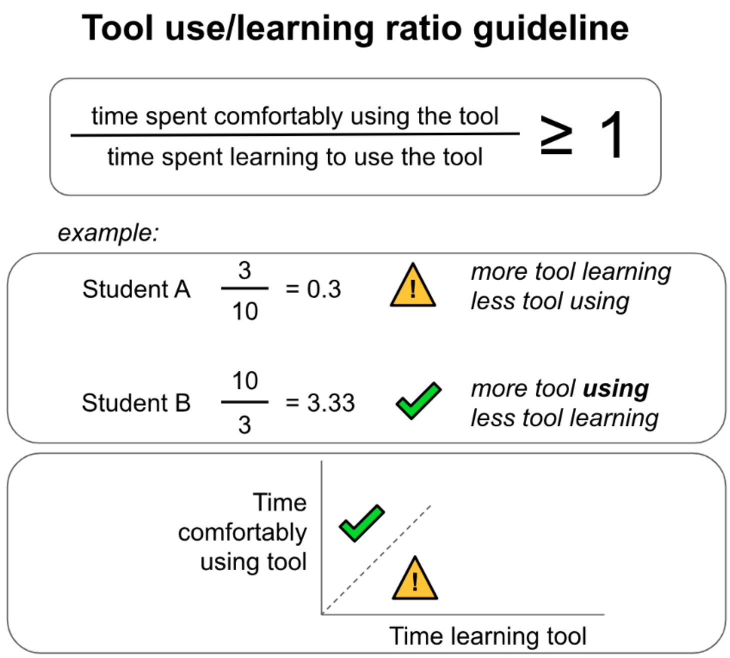

Figure 45. Tool use to tool learning ratio

Therefore, it is important to monitor students' tool learning and use experience so that efforts can be made to help them get unstuck when the tool challenge begins to overtake to the design process. The difficulty is in knowing when to intervene. It is probably impractical to track each student to such a degree while also understanding the individuals' learning dynamic and provide detailed feedback to each student. Therefore, some general guidelines for this situation may be helpful. Pause and reflect on the purpose and need for tool use. Some students tend to fixate on learning complicated tools needlessly. In this course, it appeared design tools were used in a few different ways. For design creativity, tools were typically used to (a) conduct user research, (b) model ideas, and (c) present ideas. Figure 46 below suggests these categories and some specific examples. When students begin to "spin their wheels" and become frustrated with learning curves for software, help them reflect on the larger set of tools and the various uses. For example, using the internet as a research tool can be a quick way to conduct impromptu research into a topic area and its related people.

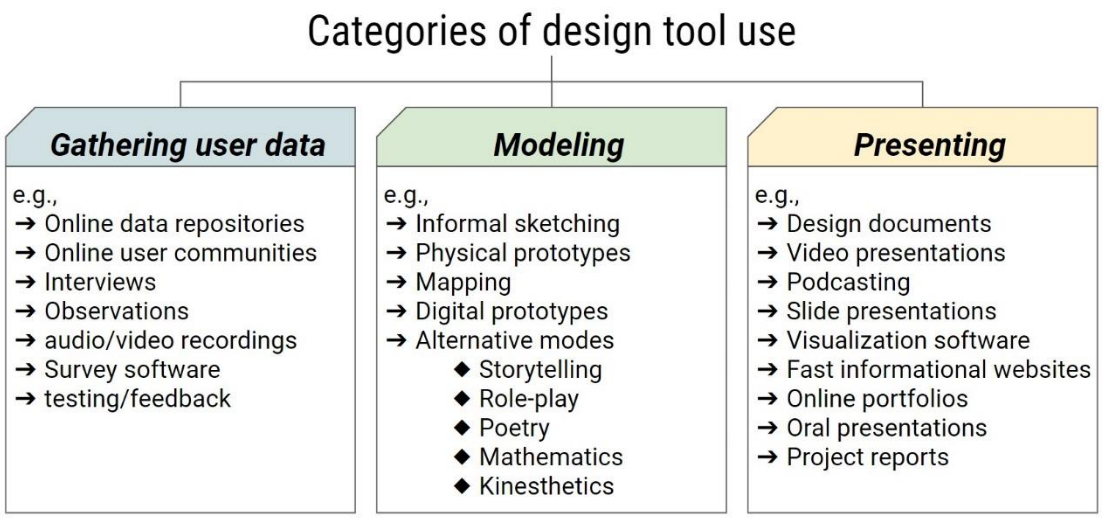

Figure 46. Design Tool Categories

Prototyping

In this course activity system, cycles of prototyping emerged as a collective learning activity. After tool use and exploration, prototyping was the most frequently referenced code throughout the student journals. Similar to the tool exploration code, references to prototyping were nearly non-existent during the week three journal entries but surged to top positions by week seven. Before prototyping emerged in this system, participants were exposed to ideas about creativity and design thinking as they explored options for what their projects would be. This preparation made prototyping, when it finally began to happen, a powerful tool for learning because it was grounded in the expression of ideas that students found meaningful. Once again, autonomy and motivation intertwined to shape and be shaped by a related factor.

It seems the belief that high fidelity prototypes were more desirable than low fidelity prototypes stalled the participants' design process. Yet, this inefficiency may be necessary for learning, as it allowed them to work through authentic problems that presented a need to weigh the advantages and disadvantages of using various kinds of prototypes to achieve their design goals. Participants coped with their preconceptions about what prototypes should be and look like. Some seemed to focus on the aesthetics of their prototypes and were unsatisfied that they did not have the “right” look. Some even believed their prototypes should be fully functional, fully coded software applications. Like learning to use the software, it took time for participants to work through these contradictions, but they all eventually seem to have done so. One participant was highly frustrated that he was unable to print, assemble, and code an operational calculator—a large task for even a skilled programmer. Eventually, he opted to create an elaborate cardboard cutout prototype and was satisfied with his process. While frustrating for the participant, this kind of experience also seemed to result in a deeper understanding of prototyping.

According to the table of class activities in Appendix F, the full concept of prototyping was not formally introduced until week five, which allowed participants to concentrate on project choice and learn about creativity during the first several weeks. They began prototyping using physical materials, and during week eight were formally introduced to digital prototyping. During the initial stage of prototyping, participant journals mostly talked about the challenge of making their ideas visible, and how reflecting on the representations of their ideas helped to clarify design ideas. Next, participants talked about how peer feedback helped with testing and iterating design ideas.

It makes sense that prototyping was so effective in moving participants’ design process forward because prototypes are a method for modeling ideas and “modeling is key to the design enterprise” (Jonassen, 2011, p. 148). During the transition from physical to digital prototypes, the challenges and frustrations with learning new software tools varied according to each participant’s software skill level. Prototyping actions provided an anchor point for idea representation, reflection, and iteration. Prototyping was also the shared action within the community that created collegial feelings and grew the culture of the learning community. Prototyping helped students: (a) make their thinking visible, (b) receive feedback, test, and iterate their designs, and (c) engage peers and build feelings of community. It was a key action the unified and grew the community.

Proposal 3. *Evidence suggests some students clung to misconceptions about prototyping and may have overly fixated on elaborating their prototypes into states of "perfection." It may be helpful to broaden the scope of prototyping to generalized modeling and multiple modes of representation of design ideas.*

Guidelines. This study did not involve microanalysis of prototyping but did find prototyping emerged as a key activity that defined the community and facilitated the development of design creativity. The good news for practice is that, of all the different activities that might be implemented in the course, prototyping appeared to broadly support development of design creativity. Not only that, prototyping activities appear to build the community. Prototyping actions provided authentic experience within the creative design process. Based on some of the challenges and frustrations prototyping posed for some students, there may be ways to support student prototyping activities without reducing the design ambiguities that seemed to promote meaningful development.

Design thinking methods often emphasize rapid prototyping and iteration (Lande, 2016; Leifer & Steinert, 2014). This approach to prototyping places greater value on speed and multiple prototype iterations than on crafting elaborate and "pretty" prototypes. Data from this study suggested a lot of students might cling to the idea that their prototypes should be visually impressive. They, therefore, may spend a lot of time elaborating or "tweaking" prototypes as opposed to using them in a disposable, iterative way. A prototyping iteration/elaboration guideline to help emphasize a rapid prototyping philosophy is suggested and represented with Figure 47.

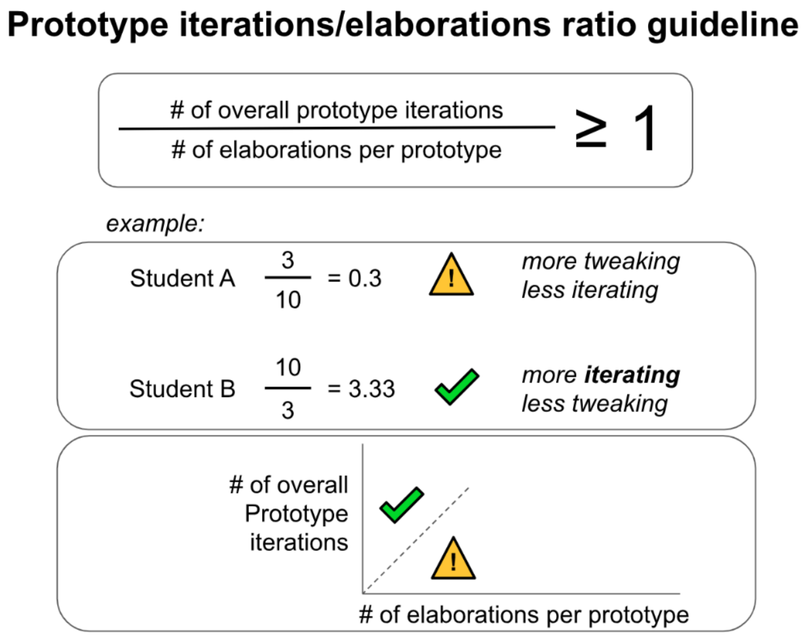

Figure 47. Prototype iterations-elaborations ratio guideline

The prototype iterations/elaborations ratio emphasizes the value of using prototypes to rapidly iterate as opposed to elaborating a single prototype with levels of detail that bog down the creative design process. For example, student A creates three different iterations of a prototype and works on ten fine-grained elaborations of a single aspect of the prototype, which is a ratio of 3:10, or 0.3. Student B creates ten different iterations of a prototype and works on three fine-grained elaborations of a single aspect of the prototype, which is a ratio of 10:3, or 3.33. A ratio of less than one indicates more efforts toward elaborating details of the prototype. Ratios that are one or more indicate a balance or more effort toward making multiple iterations of the prototype. When the larger goal is to learn and move through a developmental cycle oriented toward creative design ability, it is recommended to keep the ratio of prototyping iterations to prototyping elaborations at one or above. This emphasis is made to suggest a metric to help keep the overall creative design cycle moving. The evidence suggests students tend to fixate on the fidelity and functionality of their prototypes when it may be more beneficial to use many low-fidelity prototypes as well as multiple modes of representation of design ideas.

Prototypes make thinking visible, and there are multiple modes for making thinking visible that might also work to develop creative design ability. Within the category of prototypes, many different media are used, such as paper-based sketches, physical models, sequences of notecards, and digital representations, and for each of these mediums, there are variations. Beyond conventional prototypes, there are other ways of making thinking visible (Perkins, 2003; Ritchhart & Perkins, 2008). Concept maps make student thinking visible (Ritchhart, Turner, & Hadar, 2009.) Eppler and Kernbach (2016) described the "Empathy Map, the Business Model Canvas, Personas, Customer Journeys, or Mind Mapping" (p. 92) as common visual thinking techniques used in design thinking and explored alternatives that featured programmable, interactive digital diagrams and visualizations, which they termed "dynagrams," a term that refers to dynamic diagrams. Also, students can use storytelling to represent their ideas. Group discussions based on topics, art, music, and products can serve as ways of making thinking visible.

For example, Yenawine (2013) described visual thinking strategies based around art to elicit students' multiple perspectives and provide a format for them to wonder and be curious together. In his classic text on visual thinking, McKim (1972) provided an abundance of visual thinking activities intended to help students develop their abilities to make thinking visible within the context of problem-solving. The suggestion is that if prototyping is so powerful for shaping student development, this area could be expanded to include modes of idea representation that go beyond the conventional idea of a prototype. To expand the conventional ideas for prototyping, methods from these resources could be used.

Going beyond conventional prototypes might expand the effects of prototyping's already powerful effects on students' creative design process. A rule of thumb might be to use the guiding question: *How many ways can I represent this idea?* This question could be a starting point for the design of activities intended to expand students' prototyping methodologies. There are multiple modes of thinking—verbal, visual, kinesthetic, auditory, and more. Exploring different modes of non-verbal thinking would likely be a fruitful avenue to explore with student designers. In addition to the obvious benefits prototyping has for advancing design ideas, it also serves as a shared activity that helps students to form bonds and to learn as a class community.

Also, complicated prototyping tools should probably be avoided unless the course goal is to learn specific, specialized software. So, in addition to "What makes thinking visible?" another guideline is that prototypes should be no more complex than needed to get the idea across. When technical aspects of tool use overtook participants' focus, their thinking and actions were led by technology. Whereas for a course in creative design, *ideas* should lead to tool use—students might benefit from learning the difference between commanding technology and being commanded by it.

Archer (1979) described design as a "third area" (p. 20) of education that invoked the "executive skills of the doer and maker" (p. 20). He argued that design ought to be placed alongside the sciences and humanities and explained how its prominence as an educational domain had been lost in the shuffle of history. He pointed out that words were the language of the humanities, notation was the language of the sciences, and modeling was the language of design. His definition of modeling was broad, "A model is a representation of something" (p. 20). Prototyping is a specialized way of modeling ideas and was one of the most powerful actions observed in this course activity system. When prototyping is viewed as a subcategory of modeling, more options seem possible for making the abstract concrete and generating variations from the already powerful and effective action of prototyping.

Community

One of the most surprising findings was how pervasive social experience was throughout student development. It seems that the recurrent classroom activities and tone established by the course instructor were largely responsible for the establishment and growth of the community. But the social component of student experience extended beyond the classroom in interesting ways. Most surprising was the extent to which students brought in aspects of their personal histories to inform project choice. One participant based her project on childhood memories of gardening with her mother and grandmother and even consulted her grandmother for her project work—attributing these consultations as pivotal in her design choices. Another participant linked his project to memories of his father's occupation as a record store owner. One participant based his project on an idea from his early childhood. How these project ideas reached back into the deeply personal memories of these students is powerful and exciting—there can be little doubt this historical and personal dimension of the community added greatly to the authenticity and meaningfulness of project work for these participants. Personally meaningful projects greatly supported motivation, which added unique dimensions and depth to the community that emerged in this system.

While the social influence of students' unique experiences shaped their initial design ideas and helped to establish their motivation for project work, the classroom community took several weeks to emerge. The community became prominent and seemed to motivate participants, especially once they presented their ideas in class. Project idea presentations seemed to be a milestone event in the formation of the course's community. There were no activities that appeared similar to a pep rally. That is, the growth of the community was not forced, and the actions carried out within it were naturally extended as practical activity related to project work. This seemed to help the community to emerge in a way that was authentic and aligned with participants' interests.

The community for this course functioned as a hub for activities and shaped the other main contextual factors of motivation, tool exploration, prototyping, and creative agency. It eventually emerged as a collective and a tool that participants used as part of their expanding design methodologies. Motivation was initially attributed toward participants' choices of personally meaningful projects, but the community emerged as an equally strong facilitator of participants' motivation. The community began its influence and growth when participants presented their project ideas in class. When participants reported their tool experiences in class, the community cycle continued to grow in its influence. When in-class prototype presentations and feedback began, participants' engagement and motivation for project work were once again supported by the growing community. The community repeatedly functioned as a testbed for sharing ideas, and this cycle added to its growth and value to participants. Interestingly, gains in creative agency were found not only in participants' perceptions of themselves, but in the creativity of others. Several participants expressed new appreciation for the creativity of others as they came to value the creative insights their peers and the instructor offered as feedback on their project work. Community interactions such as this seemed to support a broad and gradual development of creative agency.

The cycle of individual exploration, presentations to the class, observations and feedback, and design choices was continual throughout the course. While this generalized cycle was consistent and repetitive, the participants' development was variable and expansive. The freedom to explore, the need to present results (e.g., ideas, tool experience, prototypes) to the class, the opportunity to observe peer and instructor reactions, and the autonomy to make design choices was the driving cycle for this system, as represented in figure 48 as a *design cycle of autonomous community* to characterize a powerful repetition of course activity. Participants had the autonomy to explore and make design choices in tandem with the support of the course community via their interactions of presentation and observation.

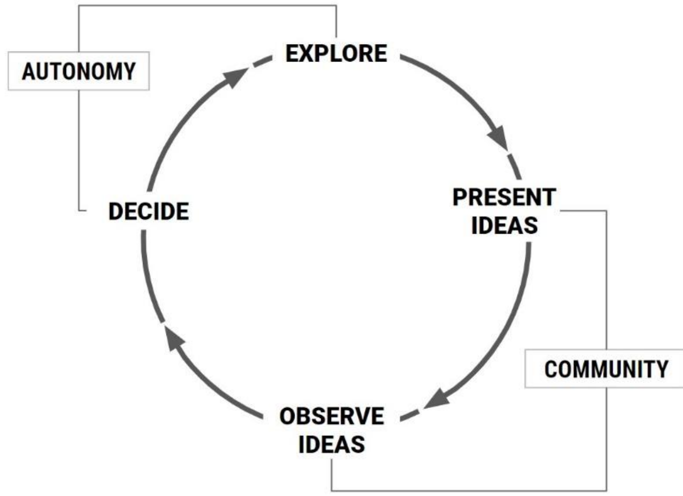

Figure 48. Design cycle of the autonomous community

Proposal 4. *Evidence suggests community takes time to form authentically and is contingent upon students' initial motivation to engage with project work. Therefore, it is recommended students have ample time to conceive their project topics. In addition, it is recommended to model psychological safety regarding creative behavior and sequence in-class activities in ways that allow learners to work through their creative design processes together.*

Guidelines. It does not seem possible to design and specify the community ahead of time because it seems to emerge organically over time and is shaped by participants. It seems reasonable that if a goal is for participants' to take ownership of the community, then they should be allowed to craft it. A helpful approach to practice might be to create the conditions that allow the community to grow and trust that it will happen. Those conditions, at least for this study, seemed to be characterized by an initial period where individuals formulate their project ideas and acclimatize to the course. This appeared to establish motivational structures that gave students the disposition to grow a culture that led to the establishment of a classroom community. After the initial phase, the introduction of prototype-oriented actions such as the (a) presentation of project ideas, (b) sharing of tool learning experiences, (c) sharing of prototypes, and related (d) feedback actions should support the growth and establishment of community. For a project-based course in creative design such as this one, it is important for the instructor to model and sustain a tone of psychological safety. This includes facilitating attitudes that are receptive, respectful, and responsive to creativity. Ideally, this would eventually result in a playful character of actions that are oriented toward the improvement of design ideas.

Because it took most participants a few weeks to choose personally meaningful projects, it is recommended to not hurry students as they try to identify their project topics. During the weeks when students are making this decision, the instructor can provide theoretical groundwork and be sure students understand basic concepts about creativity. Not all students believed that it was possible they could be creative, so it is important to help students see creativity as a potential that everyone has and that it can be developed like any other skill. At the same time, the instructor can model attitudes and behaviors that support creative behavior so that students might become comfortable with having, sharing, and refining ideas that might not initially seem acceptable or appropriate to their work. Once they gain some experience, even vicariously, in seeing how an initially rough idea can be transformed with a test and refine mindset, students may be more likely to develop the confidence (i.e., agency) to have, share, and develop their creative ideas.

The second main area for building community is the selection and sequencing of class activities. These activities can be introduced sequentially from the least to most advanced. The initial activity involves design conversations, which revolve around ideas, what they mean, and how they might be improved. Introducing design concepts such as incremental and radical innovation (Norman & Verganti, 2014) can support conditions for classroom discussions that focus on how creative ideas manifest and are refined as a way of inventing new things based upon existing ideas. Activities that promote the understanding of creativity (de Bono, 1985; Hokanson,

2018) and design methods can be used to build a conceptual framework that might support practical design activity.

While students decide on project ideas, sketching, and mind-mapping activities can be introduced as basic design tools. The first project idea presentations provide a milestone as students finally commit to their project ideas via sharing them in class. As peers provide each other with feedback, the class community builds, but it takes several weeks to do so. Students needed relaxed time to form their initial project ideas before sharing them in class. Other community builders are student presentations about tool learning experience with new design tools. The vicarious nature of these community activities helped students grow comfortable with the tool learning process and with their new group of peers.

The final and major shared activity is prototyping. Once students start bringing their prototypes to class, sharing them, and giving/receiving feedback, the community seemed to become fully functional. As usual, the instructor should model a tone of psychological safety so that students can become familiar with productive ways of talking about creative design. The students may eventually perceive the attitude and behavior well enough to conduct it without prompting. This process might build a community that is supportive of design creativity such that the community becomes a design tool in its own right that students construct and then use to improve their projects. Figure 49 summarizes recommendations for establishing a supportive community for these kinds of project-based courses.

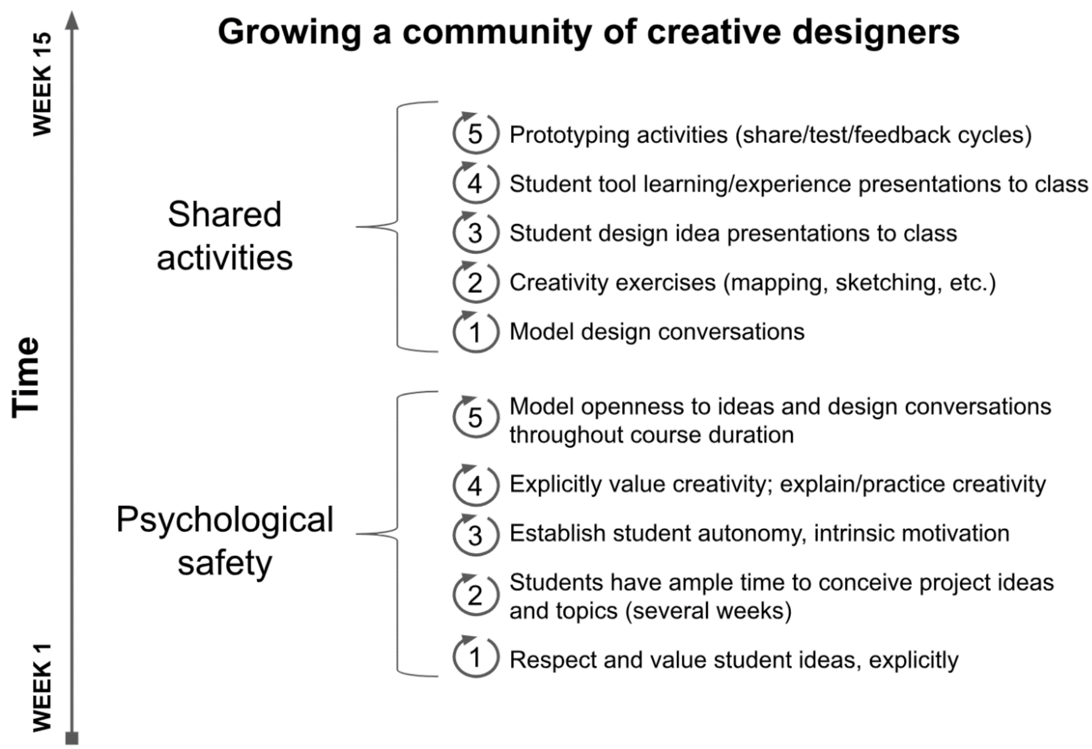

Figure 49. Growing a community of creative designers

Creative Agency

Creative agency was the most reported affective outcome for participants, and yet creativity was not explicitly mentioned until the fourth and final journal entry. Participants were prompted to reflect on their course experience via the question, *What were some of the most valuable things you learned?* Participants reported new feelings of creative confidence in themselves and a new appreciation for the creativity in others. Many students said that the course helped them realize they were creative people, and some emphasized they did not consider themselves to be creative prior to taking the course. Along with this, participants wrote about their feelings of pride, accomplishment, and satisfaction with work. How did this happen?

Autonomy appeared to strongly support participants' development of creative agency, but high levels of autonomy were only a part of the picture. Without a context for practice, it seems unlikely much development would have occurred. As it was, participants had regular opportunities for practice in class with their peers and with the support and guidance from the instructor. Planned activities guided their practice and were sequentially introduced—beginning with sketching, moving into various mapping exercises, idea and tool experience presentations, and finally plateauing with extended weeks to share prototypes while giving and receiving feedback within the in and out-of-class community. The opportunity to practice over an extended time as a design collective supported the development of participants' creative agency and confidence with the use of design tools and creative process.

The instructor was instrumental in sustaining the developmental cycle. Aside from designing and sequencing the in-class activities that supported design creativity, he introduced the course by sharing findings from the creativity literature with the participants. This involved an explanation of how the body of creativity literature supports the view that every person has creative potential and that creativity can be developed just like any other skill. In addition to sharing research findings surrounding creative behavior, the instructor consistently demonstrated the value he placed upon creativity. Considering the reports from the participants, the instructor's modeling influenced the way they valued creative practices and facilitated their efforts to use creativity as a part of their design methodologies.

When Karwowski and Beghetto (2018) investigated the link between creative confidence and placing value on creative behavior they found, "creative confidence and valuing creativity play key roles in the movement from creative potential to creative behavior for all levels of creators, even novices" (p. 12). The combination of authentic, intrinsically meaningful project work with a tone of psychological safety (Cramond, 2005; Rogers, 1954; Runco, 2007a; Schein, 1999) appears to have helped students recognize and develop creative their potential—and to recognize and value the creativity in others.

Some participants said they had not thought of themselves as creative prior to the course but came to understand creativity as a skill that could be practiced and developed. It seems a meaningful breakthrough for them was the realization that they each had creative potential. Other participants extended this description to include an appreciation of the creativity of others. Sharing and feedback actions framed the community as a creative design collective, and the participants seemed to experience firsthand what that kind of community could be like and the ways in which it could function as a creative tool within the design process. This further supports the suggestion that the *extended time* participants spent with project work, a full 15-week semester, was an important dimension for the development of creative agency.

Several terms are used in the literature to refer to various kinds of design confidence, and the primary terms applicable within this study seem to be creative confidence (Kelley & Kelley, 2013; Rauth et al., 2010) and creative agency (Dalton, 2004; Karwowski & Beghetto, 2018; Royalty et al., 2014), but there is also a close relationship of this construct to agency (Emirbayer & Mische, 1998), self-efficacy (Bandura, 1977, 1997), and creative self-efficacy (Tierney & Farmer, 2002).

The term creative agency suggests intent and action. It appeared that participants in this study developed their identities as creatives through practical activity, which was comprised of their actions and goals to accomplish project work. Therefore, this study uses the term creative agency to characterize the gains in creativity experienced by participants in this course. This is a similar idea to the one presented at the close of chapter four, where a ratio of action/affect was used to explain participant development. Creative agency is an affective state, and findings suggested its development was reciprocally determined by a productive entanglement of action, affect, and social factors.

Proposal 5. *Based on the evidence of how participants' developed creative agency it is recommended to model and share the view that all people have creative potential that can be developed just like any other skill, to provide opportunities for the collective practice of human-centered design methods, and to grant learners high degrees of autonomy in their project work to make meaningful design choices.*

Guidelines. To facilitate the development of creative agency, instructors should understand what creativity is and how it can be encouraged and discouraged in others. This requires instructors to operate more as design coaches than as evaluators, which requires an openness to student ideas. Rather than spend time evaluating student work, instructors spend time facilitating the integration of design methods and tools as activities in social contexts like classrooms and workshops. Facilitating a course environment that is conducive to the growth of a supportive community is a critical part of planning this kind of course, according to findings emerging from this study. Table 22, *Course Activities and Assignments*, offers a sequential list of the various in-class activities and assignments used to support development in this course, and descriptions of the some of the assignments are in Appendices N, O, and P. A supportive design collective, where participants freely present and share design ideas with each other, was a defining characteristic of this course activity system.

This kind of active learning design is not the norm for many educational institutions. As with most new ventures, there are unforeseen barriers. Elkind (2004) argued that successful implementations of constructivist learning are contingent upon teacher, curricular, and societal readiness. Leifer and Steinert (2014) recommend a "maximum of flexibility" (p. 171) when operating within institutional learning environments and confronting established policies that pose barriers to change. Instructors need to assess their ability to support creative behavior and the context within which they are operating before implementing course designs similar to the one explored with this study.

Not all instructors will be prepared to lead project-based courses that emphasize design creativity. Research suggests that teachers’ perceptions of creativity do not generally align with established creativity theory. Mullet, Willerson, Lamb, and Kettler's (2016) systematic review of K-12 teacher perceptions of creativity found a disparity between researchers’ and teachers' conceptualizations of creativity regarding its definition, behaviors, and development. Moreover, they found cultural differences influenced teachers’ perceptions of creativity. Although most teachers believed creativity was important, most had difficulty explaining what it is, how to recognize it, or how to assess it. Reiter-Palmon, Mitchell, and Royston's (2019) discussion of the improvement of organizational creativity recommended that leaders be trained on cognitive processes associated with creativity (e.g., problem finding, divergent, and convergent thinking) and the attitudes that support it. In courses like the one in this study, instructors are arguably more like coaches or leaders than conventional teachers, and so recommendations for management-level creativity training might also help instructors in higher education.

This study’s data suggested the successful navigation of ambiguous, and at times, frustrating states resulted in participants identifying themselves as more creative than they had once been. This result supports Royalty et al.'s (2014) findings that linked practical design activities and the resolution of negative states such as failure and ambiguity with the emergence of creative confidence. Granting students high levels of autonomy might communicate to them a degree of trust in their abilities to manage ambiguity while not being told what to do. As Elkind (1981) noted, and this study corroborated, people need time to make their own decisions and take ownership of their learning. Providing support and time while trusting learners to resolve contradictions and ambiguities could be an important way of supporting design creativity and deeper learning.

Suggestions for Future Research

With a focus on the factors that most shaped participants' design creativity, the next step for future research might be to further investigate modeling and prototyping. It could be productive to expand the scope of prototyping via specialized prototyping tools to enhance separate components of the creative process (e.g., problem finding, divergent thinking, convergent thinking.) For example, generative design techniques could be explored that begin with generating large ideational pools from which to make design choices. This might involve using software to supplement divergent thinking by generating many variations so that learners make design choices (i.e., convergent thinking) within algorithmically generated options, as is typical of parametric design (Oxman, 2017). Computers and other means could be used to augment divergent thinking. Learners could practice making creative design decisions leading to innovative outcomes that address whatever problems they identify and find compelling. How would learners and instructors experience this? Would the outcomes be more valuable than when divergent thinking is not augmented?

Another approach toward expanding the use of modeling (i.e., prototyping) would be the use of students' models and prototypes to guide the selection and discussion of instructional topics. For example, when results of project work present many possibilities for discussion, the work could be presented in the classroom community, and students' subjectivities could be used to determine topics of discussion. This approach to instructional design was tried in an earlier version of this course, where students' perceptions of the logos they made were used to identify various topics for classroom design discussions. Using learner-generated models and prototypes would be a promising way to research, expand, and tailor instructional designs.

It might also be productive to test various interventions that are intended to help learners expand the scope of their project topics. Although full autonomy in project topics was important for supporting motivation, there is a potential way of not interfering with that dynamic while also suggesting to students directions for expanding or shifting existing topics. For example, it was not uncommon for students to plateau with their design ideas, and this seems to be when they tended to become fixated on the fidelity of their prototypes—or maybe they simply ran out of ideas.

In these cases, it would be interesting to challenge students to reframe their project ideas around larger surrounding issues. If a student has designed a conventional parking app, ask them to consider the problem of transportation on a global level. If a student has designed a recipe finder app, ask them to consider the problem of food production and transportation globally and locally. How would these small challenges impact learners' motivation for project work, their self-reported learning outcomes, and the final projects they delivered? Using designed interventions to help learners connect their project ideas with social, economic, and global issues may support the expansion of their design methodologies.

Finally, another area for future research would be to test various features of the course community as ways for strengthening the already strong and positive impact it seems to have on participant development. This might include A/B testing complementary online components and additional in-class activities intended to change students' social experience within various interventions.

Shortcomings of the Study

The high-level systems approach used to explore the context of activity across 15 weeks overlooked fine-grained details that could shed more light on how creative design ability developed for students. This shortcoming was suggested when interviews provided glimpses of specific processes associated with design creativity, such as the case with the discussion of Alex's frame creation as a breakthrough in his design process. This study traded a deeper investigation into process for a higher-level contextual perspective—which is probably both a strength and a weakness of this study.

The validity of the data could be improved if there been more of a chance to member check the journal entries and interviews. Analysis of the data occurred weeks after the course was over, and students were not as available for follow-up consultations. Follow-ups with participants involving surveys or interviews could strengthen the findings of this study.

Important voices in this system were not heard. Some students did not appear to be engaged with their work in the course. They did not offer much in their design journals, and they did not make themselves available for interviews. During classroom observations, they were polite but reticent. I consulted with the course instructor about this, and he was able to confirm that yes, some students did not seem to engage. This confirmed my experience in teaching previous versions of this course. In general, most students seemed to enjoy and engage with the course, but there were usually one or two that did not seem to connect with it. This quiet set of students poses a challenge. If it were possible, it would be helpful to know what kind of learning scenarios excited them and what recommendations they might offer for course improvement.

I do not imagine there is a single reason for these students' reticence. One possibility may be that they were not comfortable with the requirement to formulate their ideas as their main work in the course. As many students reported, this was an unusual course format. It seems reasonable that while some students would be excited with an opportunity to take control of their learning path and be creative, others may dislike the idea altogether. Perhaps they believed school should provide more clear-cut procedural guidance. Perhaps they were intimidated by the challenge. Perhaps they placed no value on developing, presenting, and delivering *their* ideas.

The study may have caught a glimpse of these individuals in the interview with Scott, who enthusiastically volunteered for an interview, which turned out to last only 15 minutes—very brief when compared with the other interviews. Although this study made no effort to evaluate the qualities of the final projects, my casual observation was that Scott's project idea was minimally elaborated. And as mentioned in the findings, Scott needed special help from the course instructor to solidify is project idea. He also scored lowest on the creativity beliefs survey (O'Connor, Nemeth, & Akutsu, 2013) administered by the course instructor (and not a part of this study.) During the interview, he claimed to be using the somewhat difficult to learn software Adobe XD but was unable to provide any details on that use.

Let it be clear—there is nothing "wrong" with variances in engagement. I believe it is entirely normal and simply another facet of learning that is idiosyncratic and interesting from a research perspective. As suggested earlier on the topic of psychological safety with my reliance on Rogers' (1954) breakthrough work on creativity, it is important to accept, empathize, and not dismiss the validity of an individuals' ideas (e.g., "I don't like it" is fair whereas "It is not 'good' or 'right' is unfair and not accurate when providing feedback on creative efforts.) All of these facts taken together suggest to me that some students find creative design work especially challenging and intimidating, and it is for these individuals that a course such as this one might be profoundly transformative. As I have emphasized earlier with the help of Duckworth (1987), there is nothing easy or trivial about having and developing one's own ideas. This study would have been more valuable with more insight into participants like Scott.

Finally, it is important not to assume this quiet set of participants got nothing out of the course. In fact, if we are to believe their journal entries, they did make gains. These participants may have benefitted simply by observing their peers navigate the course. Maybe they were uncomfortable with expressing their ideas in such a format, but exposure to such a course will help them learn to develop their design creativity in the future. As it stands, it is impossible to know why some students seem to happily engage with a course of this sort while others seem a bit more tentative.

Conclusions

This study asked how participants' creative design abilities developed, what facilitated that development, and if there was evidence of creativity and design thinking. The overarching finding of this study was in how the community emerged to be a collective design tool that participants used to expand their design creativity.

Three main findings suggest how this happened and are as follows: (1) high levels of learner autonomy supported participants' motivation, (2) the course community strongly supported participants' motivation and development, and (3) development of confidence and *creative agency* (Karwowski & Beghetto, 2018; Royalty et al., 2014) required extended time. A cluster of five factors and their reciprocal growth provided the unique signature of development within the course activity system. Figure 50 shows the "big takeaways" from this study. This descriptive model consists of the cluster of factors in the 15-week course activity system that supported the development of design creativity. These results describe *what* contextual factors of the system shaped participants' creative design ability.

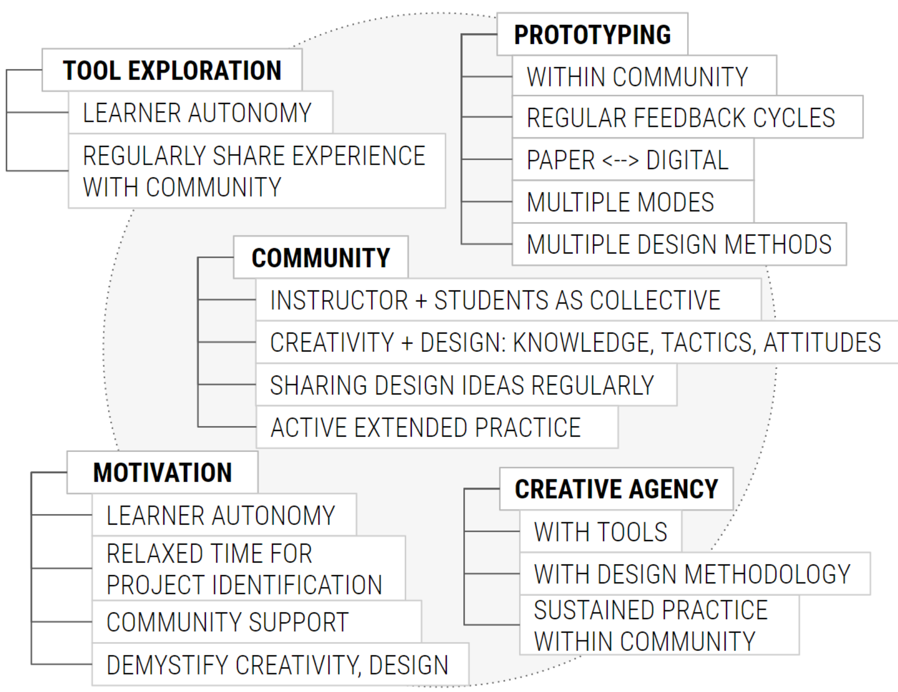

Figure 50. A descriptive model of the course activity system

The dimensions of each factor suggest *how* they influenced participant development. Granting participants high levels of autonomy and setting a tone of psychological safety in the course seemed to facilitate motivation and lay the groundwork for expansive activity. The course instructor's knowledge of principles from creativity and design thinking, ability to model creative attitudes, and ability to share tactics and methods that supported creative design greatly facilitated the development of participants' creative design ability, which is more compactly referred to as design creativity.

None of the factors existed prior to this course—they all were created through the effort of the participants and the instructor. Also, they seemed to be entangled and to reciprocally determine one another. The dialectical complexity of emergent learning environments was discussed by Jacobson and Kapur (2012), who noted methodological challenges to research posed by the co-existence of linear and nonlinear development and proposed computational agent-based modeling (Axelrod, 1997) as an innovative approach to developmental research. Although the present study does not suggest a computational model, prominent factors (i.e., variables), their interactions, and their emergence within the course activity system were identified and described. These factors might function as variables to inform the computational modeling of project-based learning environments. Because activity systems are object-oriented, findings from activity system analysis might be used to inform the data fields used in object-oriented programming.

In this spirit, Figure 51 sequentially models the main developmental factors found in this project-based humanized activity system with some of the factors' dimensions displayed along a timeline. This is a proposed model for development within similar systems. It is conceptualized in terms of sociohistorical "triangle models of activity" (Engeström, 2014, p. 231) and suggests a microcosm or a "miniature of the community from which the new activity will be based [and a] social test bench of the new activity" (p. 232). Because participant autonomy and choice is a defining feature of the model, it should be classified as what Engeström (2014) called a *humanized* activity system. The proposed model might provide fodder for what Epstein, Axtell, and 2050 Project (1996) called, “A new, *generative*, kind of social science” (p. 20).

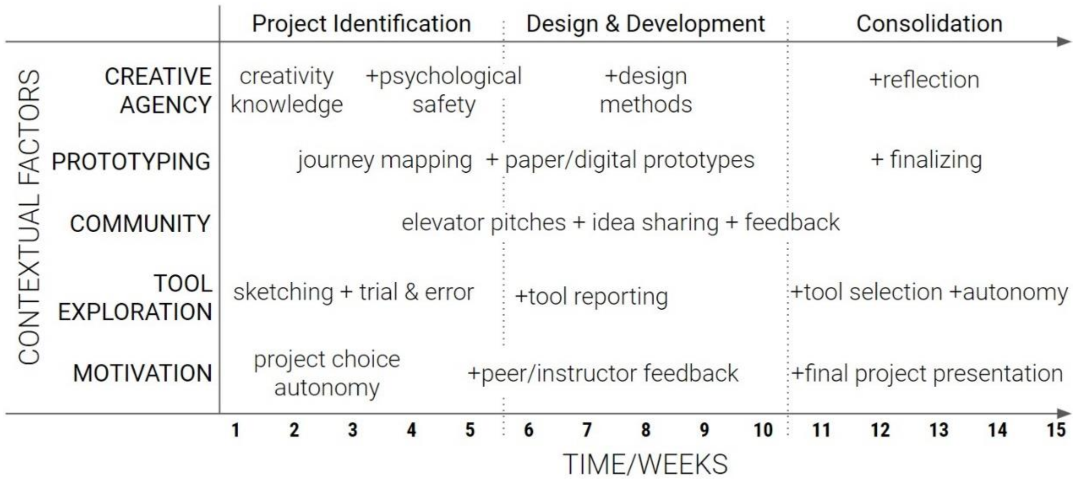

Figure 51. Humanized project-based design creativity

For those interested in integrating the findings presented here with computational models, a recent example of modeling based upon dynamic systems and triadic reciprocal determinism can be seen in Lo Schiavo, Prinari, Saito, Shoji, and Benight's (2019) work. Table 41 shows the five contextual factors that emerged from this study organized according to a triadic activity model and the six structural components of activity systems.

Because computational modeling might require establishing boundary limits and gathering values for the five factors (i.e., variables), an instrument has been developed to collect data for each of the five factors. This proposed Project Design Creativity Five-Factor Survey consists of 38 response items. Ten items are intended as repeated measures to be administered at least three times across the duration of project work. Data for the rest of the items are intended to be gathered at the end of the project work. Most items are scored with an 11-point (0-10) Likert response scale, and a few integer response items use a ratio scale. The instrument could also be used as a conventional survey to gather data for the assessment of project-based activity systems. The instrument is provided as a table in Appendix Y.

This study began with a review of the creativity and design literature that was used to generate a coding scheme to analyze participant design journal and interview data collected from participants in this course. Five contextual factors were identified as the most pronounced within the development of participants' design creativity, and their timing and emergence in participants' project work were discussed. Proposals regarding each of the factors were made, and models of participant activity in the course were shared. Recommendations for future research were suggested, and a measurement instrument was generated to collect data around the five factors and their dimensions.

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APPENDIX A:

CODEBOOK 2018-19

Code name and reference data	**Description**
Abductive logic (action) Total references: 1 Design journal references: 0 - Participants referencing: 0% Journal I through IV references: (0, 0, 0, 0) Change from Journal I to Journal IV: 0 Interview references: 0 Interviewees referencing: 20% Eric: 1, Michael: 0, Julie: 0, Scott: 1, Alex: 0	Going outside of the given data - pulling ideas from seemingly unrelated areas - making non-obvious, appropriate connections during the design process - not simply many ideas, but *logical* categorical switching. Dorst (2011) provided thorough discussion of design and abductive logic. *This code is implemented with evidence of creative design movements that seem to be "leaps" or "aha moments" where a new insight occurs that was not contained within the problem-solution space of the design problem or activity. Instances might involve going beyond the given data to formulate an original and useful design idea that adds value to the project.*
Activity theory (organizational category) Total references: 654 (aggregated from child codes)	Activity theory defines activity systems with six main categories and uses the constructs of motivation and contradictions to detect movement and change within the systems. (Engeström, 2014). *This code is not implemented or assigned; it serves as a container for its child codes.*
Co-evolution of problem-solution (action) Total references: 5 Design journal references: 1 - Participants referencing: 4% Journal I through IV references: (0, 1, 0, 0)	Creative designers demonstrate a flexibility which allows the solution and the problem to change during the creative process (Dorst & Cross, 2001).

Change from Journal I to Journal IV: 0 Interview references: 4 Interviewees referencing: 40% Eric: 1, Michael: 0, Julie: 3, Scott: 0, Alex: 0	*This code is implemented with evidence that suggests designers' are restructuring the relationship between the problem and the solution by considering different design approaches. This would typically coincide with problem-finding and reframing. It also relates to flexibility, openness, and a tolerance for ambiguity.*
Collaboration (organizational category) Total references: 16 Design journal references: 7 - Participants referencing: 20% Journal I through IV references: (1, 0, 2, 4) Change from Journal I to Journal IV: +3 Interview references: 9 Interviewees referencing: 60% Eric: 2, Michael: 0, Julie: 0, Scott: 4, Alex: 3	Collaboration. Construct from survey (Blizzard et al., 2015). “They work with many different disciplines and often have experience in more than just one field.” Statement items: “I hope to gain general knowledge across multiple fields.” “I often learn from my classmates.” *This code is implemented with mentions of working with another person on a shared object (idea or physical). Not quite the same as feedback, because not everyone collaborates as a result of feedback – some listen but do not make changes – so this is reserved for when something is done in partnership toward a shared objective.*
Community (action) Total references: 104 Design journal references: 42 - Participants referencing: 72% Journal I through IV references: (5, 8, 12, 17) Change from Journal I to Journal IV: +12 Interview references: 62 Interviewees referencing: 100% Eric:17, Michael: 8, Julie: 14, Scott: 6, Alex:17	Activity systems have communities within which subjects work to achieve objectives. In this case, the community is comprised of multiple possible groups: the classroom community, friends outside of class, family outside of class, and online resources like forums and tutorial channels. (Engeström, 2014) *This code is implemented with mentions of interactions with other people that are relevant to the individual’s design process. It is not restricted to the explicit community of the*

	classroom within a given activity system, and can include other related communities of family, friends, and online community-based resources.
Contradictions (organizational category) Total references: 137 Design journal references: 112 - Participants referencing: 100% Journal I through IV references: (2, 28, 35, 47) Change from Journal I to Journal IV: +45 Interview references: 25 Interviewees referencing: 100% Eric: 10, Michael: 1, Julie: 8, Scott: 1, Alex: 5	Contradictions occur within and between activity systems and as systemic tensions can accumulate over time. They are a "driving force of change and development" (Engeström, 2014, p. xv). *This code is implemented with mentions of challenges, difficulties, and obstacles participants face in trying to accomplish project work. Instances of contradictions can take many forms such as moments of conflict, impasse, confusion, frustration, challenge, and questioning of contextual meaning of activity.*
Convergent thinking - evaluation (action) Total references: 21 Design journal references: 16 - Participants referencing: 40% Journal I through IV references: (3, 2, 3, 8) Change from Journal I to Journal IV: +5 Interview references: 5 Interviewees referencing: 80% Eric: 1, Michael: 0, Julie: 1, Scott: 1, Alex: 2	Convergent thinking is often considered within the creativity literature as a complementary ability to divergent thinking. When faced with multiple options generated by divergent thinking, designers need to evaluate and choose among those options to achieve creative solutions (Cropley, 2006; Simonton, 2015). *This code is implemented with evidence that design decisions are being made. For example, when designers consider multiple options and finally select one. This kind of decision making can be paired with divergent thinking, but it is not necessary or assumed that is the case.*

Creative agency (affect) Total references: 32 Design journal references: 24 - Participants referencing: 40% Journal I through IV references: (0, 0, 6, 18) Change from Journal I to Journal IV: +18 Interview references: 8 Interviewees referencing: 80% Eric: 3, Michael: 2, Julie: 2, Scott: 0, Alex: 1	This category requires evidence of more than just a feeling of confidence, it requires evidence of creative behavior, actions. It is based on its related constructs of agency, self-efficacy (Bandura, 1977, 1982, 1997, 2012), creative self-efficacy (Beghetto, 2006; Tierney & Farmer, 2002), and creative confidence (Kelley & Kelley, 2013; Rauth et al., 2010; Royalty et al., 2014) *This code is implemented with mentions of confidence, pride, belief in ability to make something new or do something new- must be linked to actions, behaviors, observations, or products that are the result of creative actions. The statement, "I feel more creative" is not enough to qualify for this code.*
Creative design ability (organizational category) Total references: 509 (aggregated from child codes)	This organizational category serves as a container for constructs identified in the creativity and design literature. It is not included when ranking specific evidence from journals and interviews. *This code is not implemented or assigned; it serves as a container for its child codes.*
Divergent thinking - ideation (action) Total references: 21 Design journal references: 13 - Participants referencing: 32% Journal I through IV references: (7, 1, 1, 4) Change from Journal I to Journal IV: -3 Interview references: 8 Interviewees referencing: 80% Eric: 4, Michael: 1, Julie: 1, Scott: 2, Alex: 0	With divergent thinking, sometimes referred to as ideation, multiple options are generated. The ability to generate many options is associated with higher quality creative outcomes (Baer, 1996; Basadur, Runco, & Vega, 2000; Guilford, 1959). *This code is implemented with evidence of ideation that involves the consideration of multiple options or design ideas. Code can be extended using the constructs of originality, fluency, flexibility, and elaboration as they are applied to the assessment of divergent thinking especially within the creativity literature.*

Division of labor (organizational category) Total references: 14 Design journal references: 4 - Participants referencing: 16% Journal I through IV references: (0, 0, 0, 4) Change from Journal I to Journal IV: +4 Interview references: 10 Interviewees referencing: 100% Eric: 1, Michael: 3, Julie: 1, Scott: 1, Alex: 4	Labor is divided in various ways within and between activity systems, and the divisions are created by rules and cultural norms (Engeström, 2014). *This code is implemented with mentions of work activity, actions, and operations that run along the continuum of unified or divided. For example, if a student's project specifications are supplied externally, there is a division of labor code. At the other end, if a student's project specifications are 100% under student autonomy, there is a division of labor code. In this way this code functions as a parent code to identify specific factors that associate with division of labor.*
Emerging-new activity system (organizational category) Total references: 28 Design journal references: 18 - Participants referencing: 32% Journal I through IV references: (0, 0, 5, 13) Change from Journal I to Journal IV: +13 Interview references: 10 Interviewees referencing: 80% Eric: 4, Michael: 2, Julie: 1, Scott: 0, Alex: 3	Transformations of activity systems can result in qualitatively new thinking, practical activity, and ways of realizing the object of the activity system. *This code is implemented with mentions of new ways of accomplishing operations, actions, or activities. It is a process code and used to identify specific point in time where new ideas emerge and are represented by a subject's activity. It is used to mark instances of new ways of accomplishing work.*

Empathy - human-centeredness (affect) Total references: 74 Design journal references: 52 - Participants referencing: 100% Journal I through IV references: (31, 6, 10, 5) Change from Journal I to Journal IV: -26 Interview references: 22 Interviewees referencing: 80% Eric: 7, Michael: 3, Julie: 3, Scott: 0, Alex: 9	Design thinking is often characterized as human centered design (Rauth, Köppen, Jobst, & Meinel, 2010). *This code is implemented with mentions of other people in relation to design decisions.*
Existing activity system (organizational category) Total references: 19 Design journal references: 8 - Participants referencing: 28% Journal I through IV references: (4, 2, 0, 2) Change from Journal I to Journal IV: -2 Interview references: 11 Interviewees referencing: 40% Eric: 0, Michael: 8, Julie: 0, Scott: 3, Alex: 0	When analyzing change within and between activity systems it is helpful to note the initial states of systems and their components for comparison to a later state. *This code is implemented with mentions of pre-existing knowledge and ways of accomplishing actions and activities. It is used to establish a baseline from which to assess the development of new knowledge and ability.*
Experimentalism (organizational category) Total references: 208 (aggregated from child codes)	Experimentalism. Design thinking survey factor (Blizzard et al., 2015). “They ask questions and take new approaches to problem solving.” Survey statement item: “When problem solving, I focus on the relationships between issues.” *Deprecated. This code is implemented with evidence of inquiry behaviors such as questioning, curiosity, trial and error, hypothesizing, and/or use of the scientific method for testing design ideas.* *This code was so prevalent that it became a parent code to be elaborated by its child codes. Therefore, it is not recommended to specifically*

	assign this code but instead rely upon the child codes to reference experimentalism.
Exploring project options (action) Total references: 86 Design journal references: 63 - Participants referencing: 96% Journal I through IV references: (43, 8, 3, 9) Change from Journal I to Journal IV: -34 Interview references: 23 Interviewees referencing: 80% Eric: 5, Michael: 2, Julie: 7, Scott: 0, Alex: 9	When participants (i.e., subjects in activity systems) are responsible for identifying the final object of their activity, they need to explore their options. This is a broad code that can be elaborated by other codes like divergent thinking, problem finding, and framing. *This code is implemented when different options or strategies for final projects are mentioned.*
Feedback seeking (organizational category) Total references: 69 Design journal references: 36 - Participants referencing: 72% Journal I through IV references: (0, 3, 20, 13) Change from Journal I to Journal IV: +13 Interview references: 33 Interviewees referencing: 100% Eric: 13, Michael: 2, Julie: 8, Scott: 4, Alex: 6	Feedback Seekers. Design thinking survey factor (Blizzard et al., 2015). "They ask questions and look for input from others to make decisions and change directions." Statement items: "I seek input from those with a different perspective from me." "I seek feedback and suggestions for personal improvement." *This code is implemented with mentions of giving or receiving feedback – does not require student took the advice- efforts to seek feedback are enough.*

Feelings of surprise (affect) Total references: 9 Design journal references: 7 - Participants referencing: 28% Journal I through IV references: (1, 0, 0, 6) Change from Journal I to Journal IV: +5 Interview references: 2 Interviewees referencing: 40% Eric: 0, Michael: 1, Julie: 0, Scott: 0, Alex: 1	The correlation between surprise and creativity has been identified across a range or literature including Vygotsky's concept of *perezhivanie*. Also, the phenomena of *illumination* as described by Wallas. Cross associates surprise with significant design decisions. A surprise, a revelation, a flash of insight, a discovery. It is a marker for new and meaningful knowledge. (Smagorinsky, 2011; Wallas, 1926) Surprise can be associated with bursts of insight. It can also be associated with participants' surprise relating to themselves, such as surprise they were able to learn or accomplish something, especially if they once believed that the thing was beyond their reach. *This code is implemented with evidence of surprise that is related to project work or that is related to change in self-image.*
Framing (action) Total references: 0 Design journal references: 0 - Participants referencing: 0% Journal I through IV references: (0, 0, 0, 0) Change from Journal I to Journal IV: 0 Interview references: 0 Interviewees referencing: 0% Eric: 0, Michael: 0, Julie: 0, Scott: 0, Alex: 0	Framing involves abductive logic or making design decisions that make the creative leap from the given set of data (Dorst, 2011). For example, considering a problem from multiple perspectives and readjusting the way the problem is seen in order to achieve better outcomes. *This code is implemented when participants frame and reframe their projects in new ways in efforts to consider different approaches to design.*
Integrative thinking (organizational category) Total references: 5 Design journal references: 3 - Participants referencing: 12% Journal I through IV references: (0, 1, 0, 2) Change from Journal I to Journal IV: +2 Interview references: 2 Interviewees referencing: 40%	Integrative Thinking. Design thinking survey factor (Blizzard et al., 2015). “They can analyze at a detailed and holistic level to develop novel solutions.” Statement items: “I analyze projects broadly to find a solution that will have the greatest impact.”

Eric: 1, Michael: 0, Julie: 1, Scott: 0, Alex: 0	" I identify relationships between topics from different courses" (Blizzard et al., 2015). *This code is implemented with evidence of "big picture" thinking and considering relationships broadly and across domains of knowledge and practice. Evidence will suggest participant was thinking of how a component or the project fits into larger systems.*
Locating and using resources (action) Total references: 27 Design journal references: 17 - Participants referencing: 48% Journal I through IV references: (0, 8, 5, 4) Change from Journal I to Journal IV: +4 Interview references: 10 Interviewees referencing: 80% Eric: 0, Michael: 4, Julie: 1, Scott: 3, Alex: 2	Design thinking competencies involve locating and using resources in order to achieve design objectives (Razzouk & Shute, 2012). *This code is implemented with mentions of looking for, using, or finding learning resources of other project resources such as research data to inform design decisions. This can take the form of researching the target audience, seeking out conceptual knowledge that complements the design process, or seeking out information to aid in tool use. This can include any resources that are sought out that serve to complement the design process.*
Motivation (affect) Total references: 37 Design journal references: 18 - Participants referencing: 44% Journal I through IV references: (11, 1, 0, 6) Change from Journal I to Journal IV: -5 Interview references: 19 Interviewees referencing: 60% Eric: 0, Michael: 0, Julie: 5, Scott: 3, Alex: 11	Within and between activity systems, the objects provide the focal point for practical activity and thus orient the motivation of participants in the system. *This code is implemented with evidence of agency and intention regarding the actions and activity.*
Object (organizational category) Total references: 92 (aggregated from child codes)	Activity systems are defined by their objects. In this study the object is the final project. (Engeström, 2014) *This code is implemented with mentions of the final project. It is a parent code of motivation.*

Operations (organizational category) Total references: 3 Design journal references: 0 - Participants referencing: 0% Journal I through IV references: (0, 0, 0, 0) Change from Journal I to Journal IV: 0 Interview references: 3 Interviewees referencing: 40% Eric: 0, Michael: 0, Julie: 2, Scott: 0, Alex: 1	Operations are part of the three-level hierarchy of activity in activity theory. They are conditional to a given action and are typically carried out automatically, habitually, and sometimes unconsciously (Engeström, 2014). *This code is implemented when evidence is noted that suggests automatic behaviors are guiding actions. This might be learned habits that underpin the ways actions are carried out and can be either physical or psychological repetitive behaviors. Participants are usually unaware of these behaviors and carry them out unconsciously or without much thought.*
Optimism (organizational category) Total references: 14 Design journal references: 13 - Participants referencing: 40% Journal I through IV references: (4, 1, 0, 8) Change from Journal I to Journal IV: +4 Interview references: 1 Interviewees referencing: 20% Eric: 1, Michael: 0, Julie: 0, Scott: 0, Alex: 0	Optimism. Design thinking survey factor (Blizzard et al., 2015). “They don't back down from challenging problems.” Statement items: “I can personally contribute to a sustainable future.” “Nothing I can do will make things better in other places on the planet.” *This code is implemented with evidence that subjects' believe they can make a difference, accomplish goals, and overcome challenges.*
Outcome (organizational category) Total references: 76 Design journal references: 59 - Participants referencing: 96% Journal I through IV references: (1, 0, 1, 57) Change from Journal I to Journal IV: +56 Interview references: 17 Interviewees referencing: 100% Eric: 4, Michael: 3, Julie: 3, Scott: 3, Alex: 4	For activity theory, there are different outcomes that result in work toward the object of an activity system. (Engeström, 2014) *This code is implemented with evidence of outcomes, or the results of the actions and overall activity carried out by subjects. This could be concrete outcomes such as design artifacts or psychological outcomes such as new conceptual models and ways of thinking about the design process.*

Playful attitude fun/excitement (affect) Total references: 22 Design journal references: 11 - Participants referencing: 32% Journal I through IV references: (2, 0, 1, 8) Change from Journal I to Journal IV: +6 Interview references: 11 Interviewees referencing: 100% Eric: 2, Michael: 1, Julie: 4, Scott: 1, Alex: 3	Feelings of enjoyment, or fun, have been corelated with productive and creative work. A playful approach to design aligns with how play has been shown to be an important aspect of learning (Dewey, 1910; Rieber, 1996; Vanderschuren, 2010) *This code is implemented with evidence of enjoyment, fun, or a playful attitude towards actions and the activity.*
Problem finding (action) Total references: 47 Design journal references: 33 - Participants referencing: 80% Journal I through IV references: (25, 4, 1, 3) Change from Journal I to Journal IV: -22 Interview references: 14 Interviewees referencing: 100% Eric: 5, Michael: 1, Julie: 2, Scott: 2, Alex: 4	In the creativity literature, identification of the problem is often considered more important that problem solving (Worwood & Plucker, 2017). *This code is implemented with evidence of testing or questioning or possible causes of a problem or the factors surrounding a problem of lack of opportunity. This action can involve the questioning of a given problem and if that problem is the root cause or perhaps a symptom of a more fundamental problem impacting the situation.*
Project management (organizational category) Total references: 12	This theme emerged while reading the journal data. Managing project work appeared to be an important part of their design process. *This code is implemented when project planning is mentioned. It is a parent code.*

Prototyping (action) Total references: 99 Design journal references: 73 - Participants referencing: 92% Journal I through IV references: (1, 29, 32, 11) Change from Journal I to Journal IV: +10 Interview references: 26 Interviewees referencing: 100% Eric: 11, Michael: 2, Julie: 4, Scott: 4, Alex: 5	Prototyping is a core activity of design thinking. (Rauth, Köppen, Jobst, & Meinel, 2010) *This code is implemented with mentions of prototyping actions related to the design process. This code could be extended to include different kinds of prototypes and representations of design ideas such as sketching, modeling, storytelling, or any other means used to represent design ideas.*
Psychological safety (organizational category) Total references: 5 Design journal references: 0 - Participants referencing: 0% Journal I through IV references: (0, 0, 0, 0) Change from Journal I to Journal IV: 0 Interview references: 5 Interviewees referencing: 60% Eric: 1, Michael: 1, Julie: 3, Scott: 0, Alex: 0	Research suggests that for creative behavior to occur, attitudes and environments that support feelings that is it safe, acceptable, valued, encouraged, and respected to be creative are necessary (Amabile, Conti, Coon, Lazenby, & Herron, 1996; Cramond, 2005; Witt & Beorkrem, 1989). *This code is implemented with mentions of environments, situations, or people that make participants feel that it is okay (or not) to try to be creative. These are times when participants feel their creative ideas are acceptable and respected, or not.*
Questioning (action) Total references: 11 Design journal references: 2 - Participants referencing: 8% Journal I through IV references: (0, 0, 2, 0) Change from Journal I to Journal IV: 0 Interview references: 9 Interviewees referencing: 60% Eric: 6, Michael: 0, Julie: 2, Scott: 0, Alex: 1	Questioning can be an expression of curiosity (Berlyne, 1954; Smith, 2011) and is a child code of experimentalism. *This code is implemented for data that shows evidence of questioning, curiosity.*

Rules (organizational category) Total references: 3 Design journal references: 0 - Participants referencing: 0% Journal I through IV references: (0, 0, 0, 0) Change from Journal I to Journal IV: 0 Interview references: 3 Interviewees referencing: 40% Eric: 1, Michael: 2, Julie: 0, Scott: 0, Alex: 0	Rules define how activity is carried out in activity systems and help to define community and the division of labor (Engeström, 2014). *This code is implemented with mentions of the rules that govern the activity system. It can also be implemented with evidence that subjects' personal rules transform as a result of carrying out the activity. this might be used as part of an assessment where subjects are asked to state the rules they use to carry out a given activity. These statements could be collected throughout the activity as a way of measuring development.*
Subject (organizational category) Total references: (60) (aggregated from child codes)	Subjects are the people in activity systems who carry out activity to achieve the system's object. (Engeström, 2014) *This code is implemented when mentions of the individual or individuals engaged in the actions and activity. This can refer to demographic information or affect. This category can contain evidence of subjectivity such as feelings and beliefs.*
Survey factors (organizational category) Total references: 418 (aggregated from child codes)	The Blizzard et. al (2015) identified five underlying traits associated with design thinking. This organizational category is used as an organizational container. *This code is neither assigned nor implemented. It serves as an organizational container for its child codes.*

Time management (action) Total references: 9 Design journal references: 7 - Participants referencing: 28% Journal I through IV references: (0, 0, 3, 4) Change from Journal I to Journal IV: +4 Interview references: 2 Interviewees referencing: 40% Eric: 0, Michael: 1, Julie: 1, Scott: 0, Alex: 0	Participants need to manage time to accomplish project goals. *This code is implemented when time and scheduling issues are mentioned.*
Tolerance of ambiguity (action) Total references: 22 Design journal references: 14 - Participants referencing: 36% Journal I through IV references: (0, 2, 1, 11) Change from Journal I to Journal IV: +11 Interview references: 8 Interviewees referencing: 80% Eric: 0, Michael: 2, Julie: 2, Scott: 3, Alex: 1	Creative design is associated with a resistance to premature closure (Kienitz et al., 2014), and exploration of the problem space (Csikszentmihalyi & Getzels, 1971) and a tolerance for ambiguity (Jacobs, 2018). *This code is implemented with mentions of not knowing project direction or acknowledgements of being somewhat lost in the design process. Participants might not enjoy this feeling but would nonetheless accept it as part of the process.*
Tool exploration (action) Total references: 116 Design journal references: 81 - Participants referencing: 92% Journal I through IV references: (0, 21, 35, 25) Change from Journal I to Journal IV: +25 Interview references: 35 Interviewees referencing: 100% Eric: 5, Michael: 9, Julie: 7, Scott: 10, Alex: 4	Human development is tool mediated. Tools can include concrete and conceptual tools (Vygotsky, 1978). *This code is implemented with mentions of tool use. It is reserved for practical tools, as opposed to psychological tools like mental maps, schema, and conceptual knowledge. Other codes such as problem finding, divergent thinking, and so on help to identify psychological tools.*

APPENDIX B:

PARTICIPANT DEMOGRAPHIC DATA

There were 28 students enrolled in the course. Three students did not provide informed consent and three participants did not take this survey. Therefore, 22 participants completed this survey.

Age	Gender	College level	College major
25	M	senior	management information systems
23	M	senior	political science
23	M	senior	risk management and insurance
23	M	junior	mechanical engineering
22	M	senior	mathematics
22	F	senior	communications
22	M	senior	mechanical engineering
22	M	senior	financial international business
22	F	senior	biology
21	F	senior	consumer journalism
21	F	senior	communication sciences and disorders
21	F	senior	management information systems
21	F	senior	accounting
21	M	senior	management information systems
21	M	junior	finance
21	M	senior	finance
20	M	senior	biology
20	F	junior	psychology
20	M	junior	management information systems and economics
20	F	junior	cellular biology
19	M	sophomore	accounting
19	F	sophomore	communication sciences and disorders

Note: n = 22, three participants not reporting

APPENDIX C:

STUDENT CHOICE TOOLS

The following is a list of tools students reported using for their design work during the course. This data was collected with survey form C. There were 28 students enrolled in the course. Three students did not provide informed consent and therefore 25 participants completed this survey.

Tool	Category
AutoCAD	3D and 2D design and drafting software
TinkerCAD	3D design, electronics, and coding
Paint 3D	3D modelling application
makerspace	3D printing lab
Powtoon	animated presentations and animated explainer
the noun project	graphic library
Photoshop	image editing
pixlr	image editing
Pixomatic	image editing
3D printer	object creation
cut-outs	physical prototype components; conventional
paper	physical prototype components; conventional
LabView	system-design platform and development environment for a visual programming language
Adobe XD	user experience design software application
mockflow.com	user experience design software application
Marvel App	user experience design software application

Lynda.com	video courses in software, creative, and business skills
YouTube video editing tools	video editing browser-based software
iMovie	video editing software

APPENDIX D:

FALL 2018 SYLLABUS

EDIT 4020 – Technology for Innovation in the Workplace
COURSE SYLLABUS – Fall, 2018

Tuesdays & Thursdays 12:30PM-1:45 PM/ 2:00PM-3:15PM 0409 Aderhold Hall

Contact Information [instructor's email address]

Office Hours
Tuesday & Thursday by appointment

Course Description

This course is designed to tap your creative potential and help you learn and practice design thinking in an engaging and interactive way. Magic performance will be applied to this class to facilitate your creative design thinking process. It doesn't matter how much previous design experience you had. A series of engaging activities will be provided to enable you to think like a creative designer and develop your own innovative products. Specifically, you will decide a project that is meaningful to you and choose whatever technology or tools you prefer to design and build it. Every student in this class is regarded as independent learner and designer. I hope this class is meaningful to everyone. Hopefully, it will produce a positive influence on your life.

Accommodations

This course follows the regulations outlined in the Americans with Disabilities Act. Call UGA Disability Services at (706) 542-8719 (voice) or (706) 542-8778 (TDD only) for information about architectural access and to arrange for sign language interpreters, assistive listening devices, large print, audio, or Braille. Students requiring special accommodation should contact the instructor as soon as possible.

Attendance/Participation

Class attendance is essential for your success with this course. Attendance counts towards your participation grade and is expected on a regular basis. Everyone get 2 absence. If you have to miss the class, please email the instructor. Missing more than four classes may result in a WF for the semester.

Expectations on Participation. I expect you to come to the class prepared and to contribute to class discussions and activities. I value your personal experiences and expertise. You will never know who will benefit from your ideas unless you share them with us. I believe that every student has the power of inspiring all of us. So please feel free to share!

Readings

There are not a lot of *readings* for this course, but the readings that we do have are important to your intellectual development about design and creativity. All readings come at the beginning of the course. For each reading, you are required to write a brief reflection about it. The reason for this is so that you can begin to build some knowledge of the design literature and let it mix with your own instincts and ideas while you do the actual work of conceiving and implementing the project of your choice.

The Goals of This Class

- Develop skills and confidence in generating and refining creative ideas.
- Apply creative design thinking to the personal design process.
- Be able to find and use tools to realize design ideas.
- Develop skills in demonstrating and communicating design ideas.
- Become an independent learner.

The Idea Generation and Design Process

Idea Marathon is an ongoing activity that encourages you to generate and refine your creative ideas. You will receive a notepad, which allows you to record your ideas in the way you prefer (such as drawing, describing, etc.). The goal of this activity is to help you form a habit of developing and organizing creative ideas.

Elevator pitch is your first attempt to describe your idea in a way that is persuasive to your audience. During class, students will come to the front of the room and use 3 minutes to describe their project ideas.

Design Journals are for keeping track of your project ideas and for receiving formative feedback from me and/or your peers. In general, each entry should take about 15 minutes to write and 5 minutes to read; that's why they are also called "15/5s." As you begin to build your design, include screen shots to help the reader understand your work and ideas.

Desk Crits are the feedback you will give to your peers on their project work (and the feedback they will give to you.) This happens during live class when we set aside time to look at each other's project work and give critique.

Tool reports are 1 to 3-minute video reports (I am also open to other reporting ways) that document what tools you are considering to use for your project and why. Once you have selected a toolset that matches your interests and project objectives, you will move on to describe what it's like to use the tool. Why this tool? What are you trying to accomplish with it? What's good about it? What's not so good about it? And so on. Delivering narrated video reports is a technical skill we will all master this semester.

Your *beta test* is during the last third of the course and when your project is really taking shape. Your project is well-formed enough so that you can test it out with other people (show it to them and let them play around with it.) It is not a final product quite yet, but it's close. And you need feedback from others to polish it off and present it as final.

Your *final prototype demonstration* will be conducted in an authentic environment. We will invite guests to our class. You will introduce your prototype and ask them to interact with it and leave you feedback. This is a chance for you to practice your communicating and marketing skills. Your final prototype *does not have to necessarily be functional*. For example, if you choose to design a mobile app it doesn't need to work on a device; that kind of programming is beyond the scope of this course. Just because you don't know how to program it, don't let that stop you from designing it! Let your imagination be the limit here; for this course *ideas are more important than technology* (although we use technology to research, design, and deliver product designs and prototypes.) We will learn how to make *interactive prototypes* of design ideas: mock-ups of your page designs and how they flow when users click through them. However, if your skills *are* programming and you want to use 4020 as a place to try out some programming ideas- that's great too, you're in the right place. Pick a project idea that you think you will have fun with, that is interesting to you personally. Everything else flows from there. You have several weeks at the beginning of the course to decide what your project will be so don't feel rushed; entertain as many ideas as possible before you pick one for your final project idea.

Your *final project* is the result of all your work in the course. You will use the website building tool (i.e., WordPress) to make a portfolio which includes your design process (design journals, prototypes, etc.) and your final prototype. Your project idea is your own choice. Early in the course (the first third of the course) and throughout you will decide what your project will be. It's important this project is interesting to you personally and fits with your career goals.

This is project-based learning combined with social constructivism. Enjoy and take advantage of your freedom to identify and pursue a project that means something to you. I am here to help you as are your peers, but it's up to you to choose and pursue a project idea. My goal is to help you through a process that results in a meaningful and persuasive final project. This class is a collaborative environment and an incubator for good ideas. Be present, thoughtful, and follow your instincts.

Acknowledgements

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EDIT 4020 Assignment Map

Participation (25% of 100)	**Readings + Reflections (15% of 100)**	**Tools (15% of 100)**	**Project (45% of 100)**
Class Attendance 10 points	*Reading + Reflection #1 5 points*	*Tool report #1 5 points*	*Design Journals (5x) 10 points (2,2,2,2,2)*
In-class activity *10 points*	*Reading + Reflection #2 5 points*	*Tool report #2 5 points*	*Elevator pitch 5 points*
Idea Marathon 5 points	*Reading + Reflection #3 5 points*	*Tool report #3 5 points*	*Beta Prototype 5 points*
			Final Prototype 5 points *Final Project and Documentation 20 points*

Specific deadlines are subject to change to accommodate your learning needs, and they will be announced well ahead of time.

The following scale is used to assign grades:

A	100%	to 94.0%
A-	< 94.0%	to 92.0%
B+	< 92.0%	to 87.0%
B	< 87.0%	to 84.0%
C+	< 84.0%	to 77.0%
C	< 77.0%	to 74.0%
C-	< 74.0%	to 70.0%
D	< 70.0%	to 64.0%
F	< 64.0%	to 0.0%

APPENDIX E:

STUDENT PROJECT TITLES, TITLES, TYPES, AND TOOLS

There were 28 students enrolled in the course. Three students did not provide informed consent and therefore 25 participants completed this survey. This table combines data gathered from

Student major (n=25)	Project title	Project topic	Project type	Tools used
Consumer journalism	Travel Easy	travel	mobile app	pixlr, Marvel App
Mathematics	Between Bikes	transportation	product with mobile application	Marvel app, Adobe XD, pixlr.com
n/a	Shuttle bus?	transportation	mobile app	0
Accounting	Capacity Spot; All in one parking app	transportation	mobile app	Adobe XD
Political science	Park Buddy	transportation	mobile app	Adobe XD, Lynda.com
Communication sciences and disorders	Eat Now! let's eat now! where should we eat?	food	mobile app	Powtoon, Marvel App, Adobe XD
Communications	PT (Personal Trainer)	exercise	mobile app	Adobe XD
Mechanical engineering	Redesigning the Solar, Solar Tree	solar energy design	product design	AutoCAD, LabView, Hardware (panel, lens, data acquisition device, etc.)
Biology	Mop Socks / How Clean	cleaning supplies	product plus mobile application	Adobe XD, Marvel App
Psychology	Unwritten	Creativity tools - fiction creation software	mobile app and website	Marvel App, Pixomatic
Financial international business	Music Jack Earphones headphones	device accessories	physical - earphone organizer	Marvel App

Risk management and insurance	Ultimate Trivia	educational games	mobile app	mackflow.com, Marvel App, screenshot
Biology	ModStand	device accessories	physical - device clamp	3D printer -, makerspace
Mechanical engineering	Ez-slide / guitar gloves	musical equipment	product design	Adobe XD, pixlr
Management information systems and economics	College Buddy	productivity	mobile app	Marvel App
Management information systems	UGA Parking app	transportation	mobile app	Marvel App, Photoshop
Management information systems	FreeBoard	network communication technologies	website app	Paint 3D, Adobe XD, the noun project, Marvel App
Mechanical engineering	Ti-dx	computing devices	physical - specialized calculator	AutoCAD, 3D printer, Marvel App
Accounting	ShoeMe	online retail	mobile app	Adobe XD
Management information systems	Opposed piston engines	automotive engineering	product design	3D print, TinkerCAD, Video (YouTube), iMovie
Finance	Cardio DJ BPMUSIC	music	mobile app	paper, cut-outs, Adobe XD
n/a	Froomie	housing	mobile app	Adobe XD, Photoshop
Cellular biology	The Stabilizer HQ	medical devices	product	Adobe XD,#D printer, youexec
Communication sciences and disorders	Garden Guru	landscape design	mobile app	Marvel App, Adobe XD, Pixlr
Finance	Park Pro, SMART Park	transportation	product with mobile application	Adobe XD, Pixlr

APPENDIX F:

IN-CLASS PRESENTATION TOPICS AND ACTIVITIES

Presentation number	Presentation topics	Week
1	Introduction to class	1
2	Creativity drawing alternative uses task Thinking fixation Principles of magic in relation to creativity Creative confidence	1
3	Creative confidence Creativity Do one thing you never did before or do it differently: 1. Take a photo or record a video of it. 2. Upload to our class wall and share your creative experience in our next class.	2
4	Design Thinking: Know your audience Empathize - Define - Ideate - Prototype - Test Empathy Redesign the gift-giving experience Sketch and share activity (idea sharing)	2
6	Idea expansion and development Tool sharing activity Visual thinking concept maps mind maps brainstorming project ideas divergent thinking advanced concept map for designers - Journey Maps	3
7	Make your idea unique Tool sharing activity Problem-solution and final project expectations 4 problem-solution types Type 1: new problem and new solution Type 2: new problem and old solution* Type 3: Old problem and new solution* Type 4: Old problem and old solution *final projects are expected to by either Type 2 or type 3 challenge design assumptions Introduction of Creative Design Guideline assignment	4

8	Promotional video making Journey maps and creative design guideline shared Google Drive folder introduce individual talk activity and sign-up sheet introduce tool sharing resource list (shared Google sheet) student tool sharing activity (student tool presentations) narrative structure for promotional videos introduce PowToon for making and delivering video reminder of upcoming elevator pitches (project idea presentation)	4
9	Elevator pitches - reminder and order of student presentations introduce 3D printing resources and training individual talk activity (student presentations) tool sharing activity (student presentations) Effective PowerPoint presentation tips	5
10	Prototyping practice Elevator Pitches Design thinking practice (Empathize - Define - Ideate - Prototype - Test) reminder of promotional video assignment Tool sharing activity (student presentations) individual talk activity (student presentations) paper plane activity Design challenge: find the right design problem + find the right design solution + problem framing Design activity: making idea prototypes with clay, sticks, crayons, and paper	5
11	Design thinking practice II Tool sharing (student presentations) Individual talk (student presentations) rapid prototyping different types of prototypes (levels of fidelity) needs analysis - identify the real design problem idea generation (mind mapping, concept mapping) Design activity: making idea prototypes with clay, sticks, crayons, and paper Role play activity: modelling testing and feedback - refinement and improvement Magic challenges to test and improve creativity	6
12	Paper prototypes Prototyping your product tool sharing (student presentations) 3D printing campus resources review design journal #2 project ideas and emergent challenges/contradictions individual talk (student presentations) prototyping with index cards thinking flexibility low vs high fidelity prototypes using concept and journey maps to generate paper prototypes	6

13	Design problems Prototyping tool for 3D printing reminders: promotional videos and design journals due today tool sharing activity (student presentations) individual talk (student presentations) problem-solving practice/examples 3D software: tinkercad.com 3D resources: thingiverse.com	7
14	Prototype testing 3D workshop reminder (optional) tool sharing activity (student presentations) individual talk (student presentations) design principle: error tolerance design prototype testing (give/receive feedback)	7
15	Improving prototypes - upgrading tool sharing activity (student presentation) individual talk (student presentations) Design cycle: design - test - refine Failure as part of the design process: improvement of design - refinements Prototypes: transition from physical to digital with Marvel app Video: making screencast videos with screencast-o-matic Tool reports: description of assignment and reminder	8
16	Add surprise to your prototype tool sharing activity (student presentations) individual talk divergent thinking design principle: surprise design practice activity design tool selection digital prototyping	8

APPENDIX G:

DATA COLLECTION SCHEDULE

Data source	Date	Data collected	Location
Survey	Week 2 8/21/2018	Demographic data; attitudinal data	on site
Survey	Week 2 8/21/2018	design thinking traits; 9 item, 5 scale Likert	on site
Journal 1	Week 3	text; 256 avg word count; 158 codes	LMS; online
Field notes	Week 6 9/18/2018	Observational data from student project pitches	on site
Journal 2	Week 7	text; 198 avg word count; 142 codes	LMS; online
Field notes	Week 9 10/9/2018	prototype information; images	on site
digital prototypes	Week 11	screenshot images	online website
interview 1	Week 12 10/30/2018	face-to-face audio recording; 31m:34s	on site
interview 2	Week 12 10/30/2018	face-to-face audio recording; 46m:33s	on site
Journal 3	Week 13	text; 234 avg word count; 195 codes	LMS
interview 3	Week 14 11/13/2018	face-to-face audio recording; 15m:43s	on site
interview 4	Week 14 11/13/2018	face-to-face audio recording; 32m:57s	on site
interview 5	Week 14 11/27/2018	face-to-face audio recording; 32m:35s	on site
design thinking traits survey post-test	Week 15 11/27/2018	design thinking traits; 9 item, 5 scale Likert	on site
exit survey	Week 15 11/29/2018	journal opinion, design definition, project info	on site
Journal 4	Week 15	text; 348 avg word count; 315 codes	LMS

Field notes	throughout the course	Observational data from course final showcases; two course sections	on site
informal conversations with instructor	throughout the course	researcher notes during and after conversations	on and off site

APPENDIX H:

SURVEY FORM A

Student demographic survey

What is your name? (First, Last)

What is your current student status? (circle one)

College freshman   College sophomore   College junior   College senior

---

Is this course required for your major, or are you taking it as an elective? (circle one)

Required   Elective

What's your major? (write in)

What is your gender? (circle one)

Male   Female

How old are you? (write in)

Student instructional preferences

What is your general preference about in-class activities organized and required by an instructor? (check one)

- ☐ I like it when the instructor asks students to complete in-class activities.
- ☐ I don't care either way if the instructor asks students to complete in-class activities.

- ☐ I don’t like it when the instructor asks students to complete in-class activities.

What is your opinion about using technology directly for instructional class activities? (check one)

- ☐ I’m in favor.
- ☐ I don’t care.
- ☐ I’m not in favor.

What is your opinion about how much or how often technology is used directly for instructional activities in your college experience? (check one)

- ☐ Technology is used too often.
- ☐ The use of technology is about right.
- ☐ Technology is not used enough.

Creativity survey administered by course instructor

Tip: Reflecting on your experience before taking this course, how much do you agree with the following statements?

“You have a certain amount of creativity and you really can’t do much to change it.” (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

“Creativity can be increased and fostered through hard work and personal effort.” (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

“You are stuck with whatever amount of creativity you are born with.” (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

“It is easy to increase one’s creativity through practice and education.” (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"Your level of creativity stays the same throughout your lifespan." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Design thinking traits pre survey (nine items) **(Blizzard et al., 2015)**

"I seek input from those with a different perspective than me." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"I seek feedback and suggestions for personal improvement." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"I analyze projects broadly to find a solution that will have the greatest impact." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"I identify relationships between topics from different courses." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"I can personally contribute to a sustainable future." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

"Nothing I can do will make things better in other places on the planet." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"When problem-solving, I focus on the relationships between issues." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I hope to gain general knowledge across multiple fields." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I often learn from my classmates." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

Design thinking self-assessment

"I am familiar with design thinking and know how to use it." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

Thank you for completing the survey!

APPENDIX I:

SURVEY FORMS B AND C

Survey form B (Tuesday, 11/27)

Design thinking traits post survey (nine items) **(Blizzard et al., 2015)**

"I seek input from those with a different perspective than me." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I seek feedback and suggestions for personal improvement." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I analyze projects broadly to find a solution that will have the greatest impact." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I identify relationships between topics from different courses." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I can personally contribute to a sustainable future." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"Nothing I can do will make things better in other places on the planet." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"When problem-solving, I focus on the relationships between issues." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I hope to gain general knowledge across multiple fields." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

"I often learn from my classmates." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

---

Project idea generation survey (three items)

1. When did you first get the idea for your final project?
2. When did you finally decide that idea would be your final project idea?
3. Did you consider multiple ideas for your project? If so, how many?

Survey form C (Thursday 11/29)

Project information (three items)

1. What's the name/title of your project?
2. What tools (software or something else) did you use to design your project?
3. Who is your project for? That is, who is the target audience?

Design thinking self-assessment (one item)

How much do you agree with the following statement?

4. "I'm familiar with design thinking and know how to use it." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Project information (three items)
How much do you agree with the following statement?

5. "My design journal entries helped me think and learn about design." (circle one)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

6. Please complete the following sentence beginning.

"Design is …

Thank you for completing the survey!

APPENDIX J:

FALL 2018 DESIGN JOURNAL PROMPTS

Design Journal one (Week three)
Work this semester revolves around designing and developing your final project, and this series of journal entries begins a kind of diary or design journal for your project ideas and work.

You're not expected to have an idea what your project might be at this point (although it is fine if you do.) Your job with this entry is to identify your interests that might help focus your project's direction. It's best if your project is personally meaningful to you, so take advantage of the freedom to choose a project topic of interest to you personally, professionally, or both.

What are some project ideas you have? What are the magical effects of your project ideas? Who are your possible target audience? What would you like to accomplish with those ideas? (About 300-400 words)

Design journal two (Week seven)
We've talked about creativity and design thinking. Everybody has creative potential, and some basic principles of design thinking are that it is human centered. Now you should have identified your target audience, the kind of problem(s) they are experiencing and your possible design solutions. It is time for you to think about how you are going to realize your idea. In your design journal, try to answer the following questions:

Do you have a plan yet for building it or developing a prototype? What software tools might you use? What are some of the difficulties, challenges, or frustrations you're working through at this point?

Design journal three (Week 13)
By now you have made prototypes of your project. How do you feel about your progress so far? Are you still letting the target users and the problem(s) they are experiencing help guide your design and development process? What questions have you had to resolve, or perhaps still continue to remain open? What tools are you using to design and build? What are some of the difficulties, challenges, or frustrations you're working through at this point? What are some of the successes?

Design journal four - reflection (Week 15)
Take a look back to the beginning of your work in this course and think about the progress you made to reach your final project. What was it like? Were there periods of confusion? Were there

challenges? Did you experience any stress? Describe these feelings and what you did to move through them with your work. What were some of the most valuable things you learned? How might your experience in building your project affect the way you use technology in the future?

APPENDIX K:

INTERVIEW QUESTIONS

Interview Questions

1. Would you talk a little about what your project is and how you got the idea for it?
2. Where there any challenges you encountered in your project work?
3. Were you able to resolve those challenges? How? Or, why not?
4. What tools did you use to make your project?
5. Did you feel like you had the freedom to do the kind of project you wanted to do?
6. Did anyone influence your project work?
7. What does “design” mean to you?

APPENDIX L:

DESIGN THINKING TRAITS SURVEY

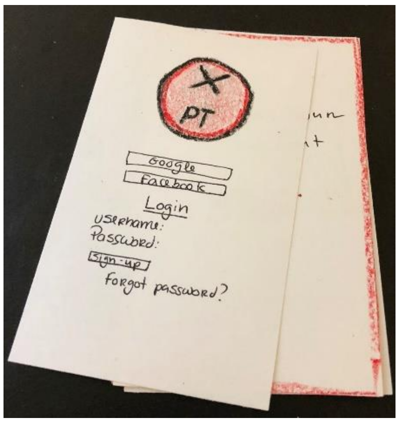
Design Thinking Traits Survey (Blizzard et al., 2015)

What is your name? (Last, First) ___________________, ____________________

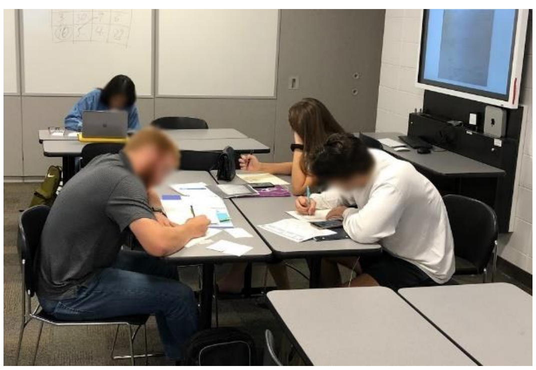
Please show how much you agree or disagree with each statement below.	Strongly agree	Agree	Mostly agree	Mostly disagree	Strongly disagree
I seek input from those with a different perspective from me.					
I seek feedback and suggestions for personal improvement.					
I analyze projects broadly to find a solution that will have the greatest impact.					
I identify relationships between topics from different courses.					
I can personally contribute to a sustainable future.					
Nothing I can do will make things better in other places on the planet.					
When problem-solving, I focus on the relationships between issues.					
I hope to gain general knowledge across multiple fields.					
I often learn from my classmates.					

APPENDIX M:

IN-CLASS PROTOTYPING



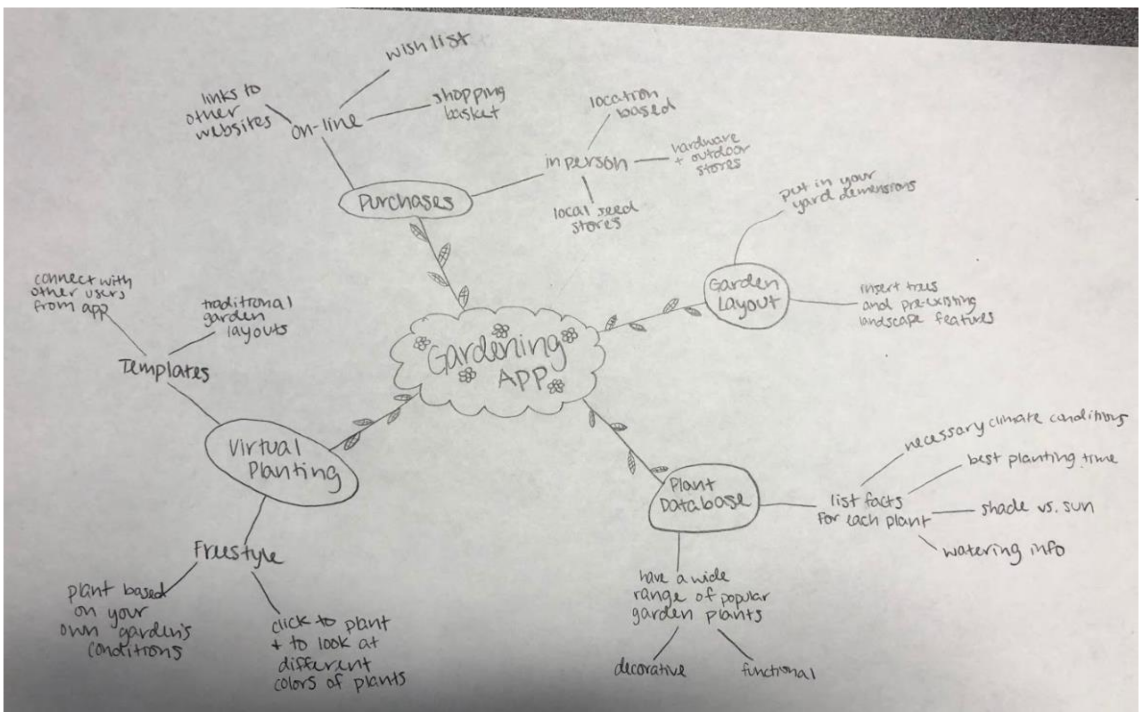
Paper prototyping with index cards

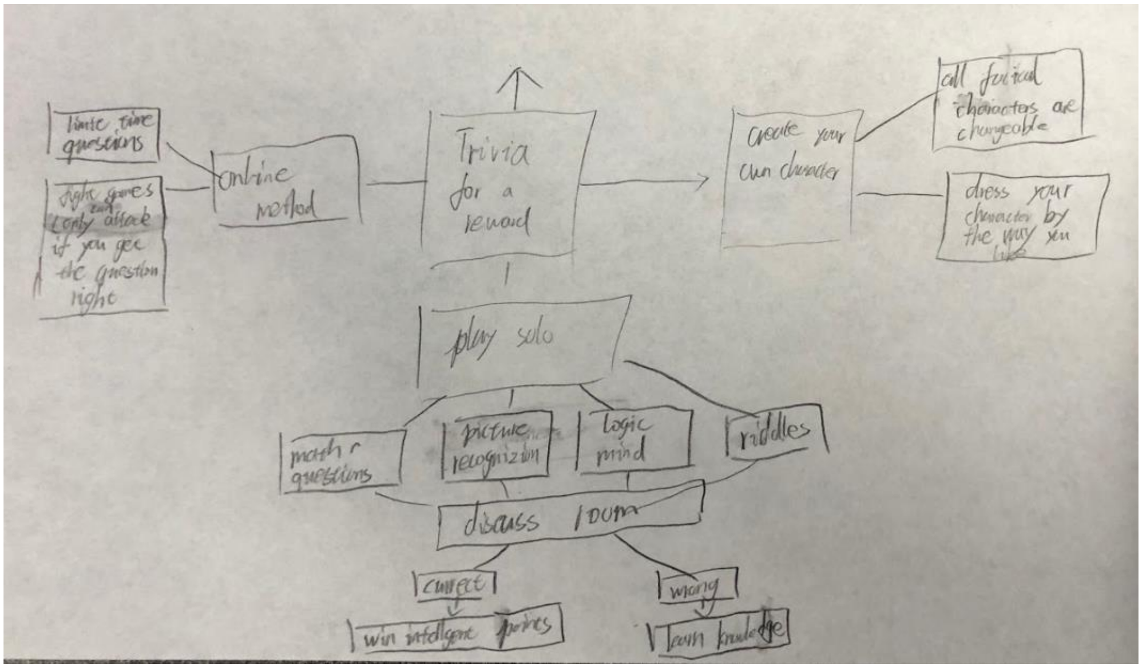


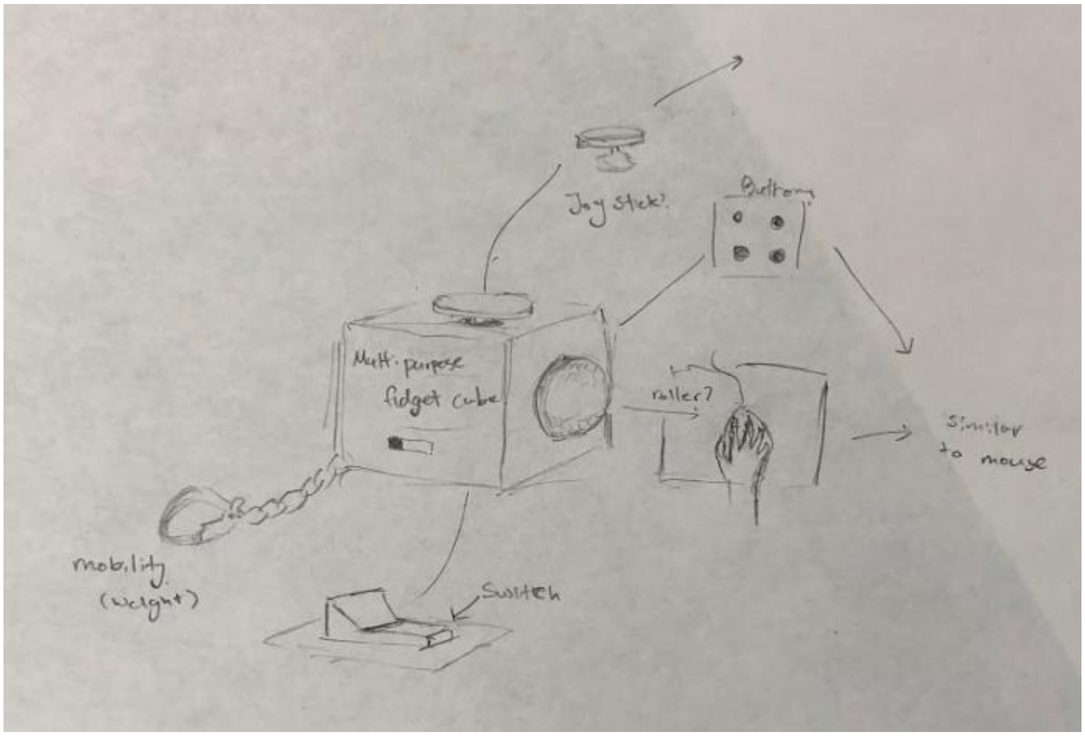
Prototyping activity
– concept mapping and mind maps

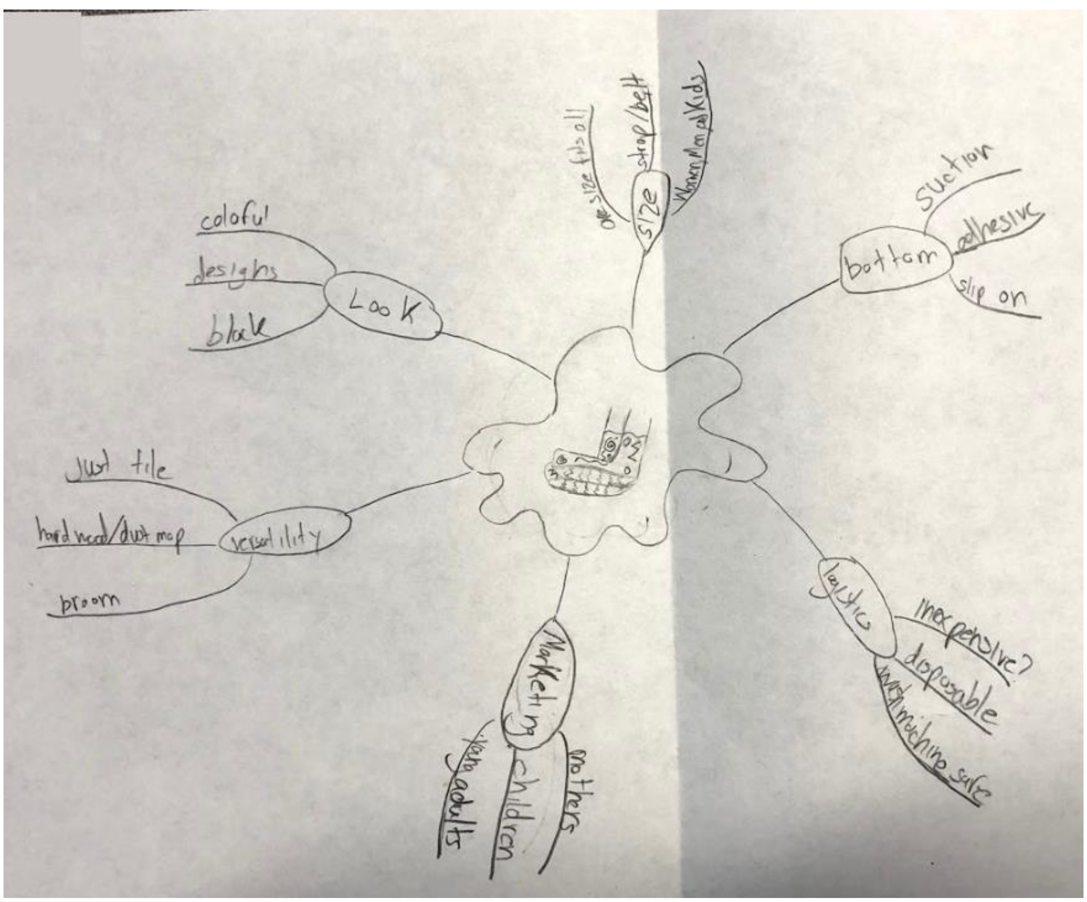
Prototyping activity

- *Peer feedback (giving and receiving)*



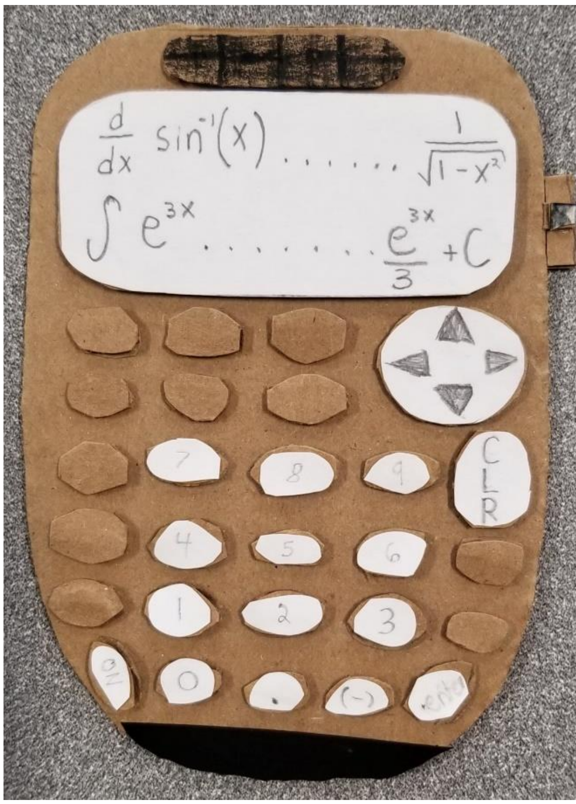

Trivia for a reward
online method
play solo
riddles
logic mind
discuss room
correct
wrong
learn knowledge
dress your character by the way you like
create your own character

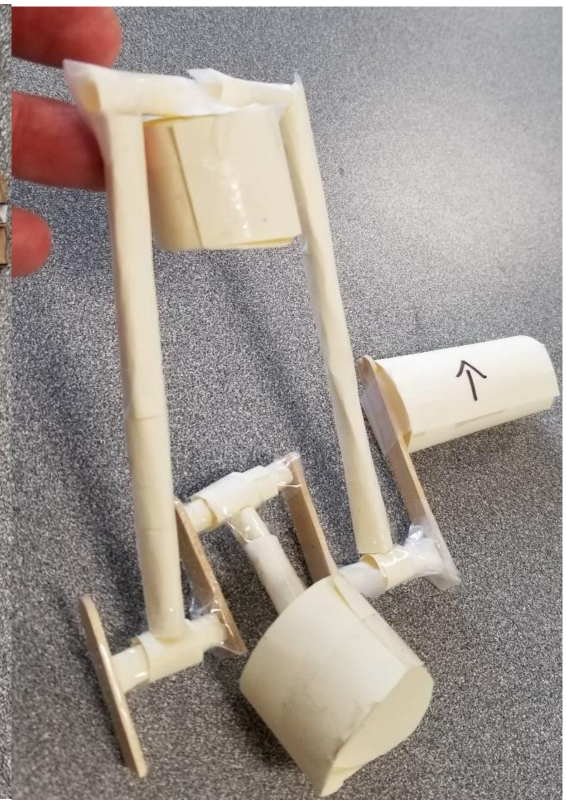

Joy stick?
Buttons
Multi-purpose
fidget cube
roller?
Similar
to mouse
mobility
(weight)
Switch

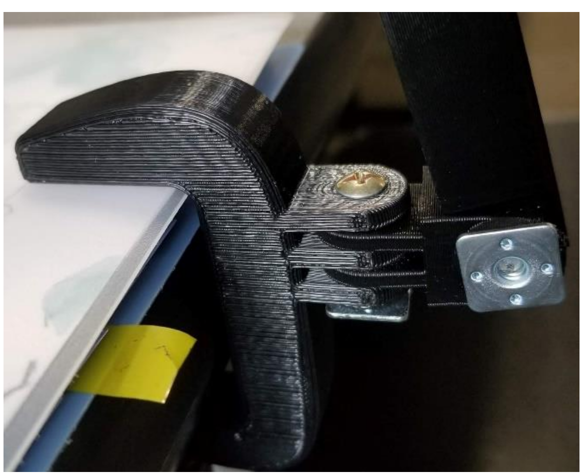

Look
colorful
designs
black
size
bottom
suction
adhesive
slip on
just tile
hard wood/dust mop
versatility
broom
Marketing
mothers
children
adults
inexpensive?
disposable
washing machine safe

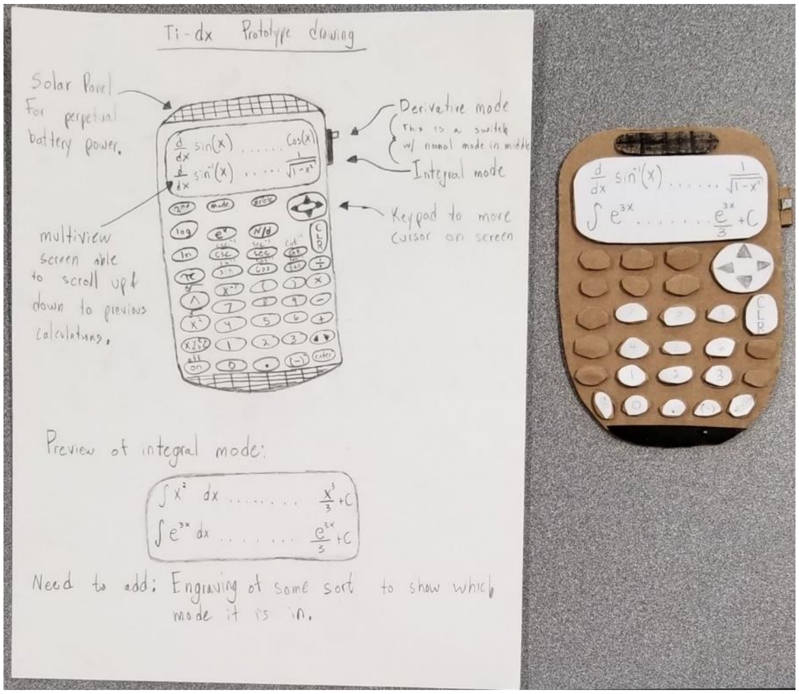
APPENDIX N:

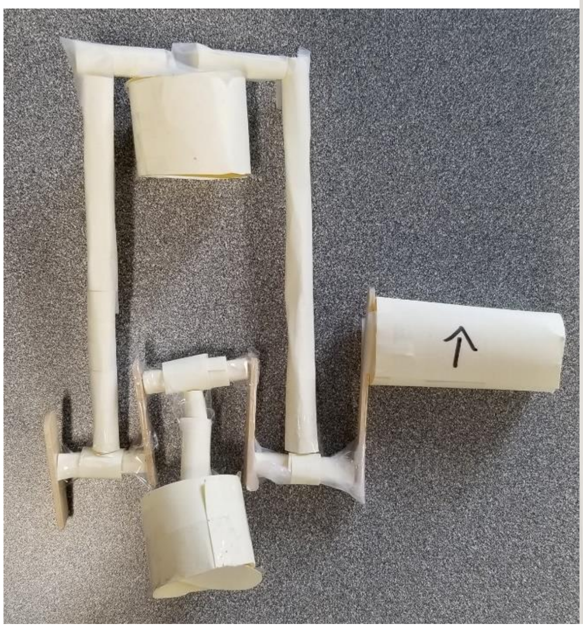
WEEK 12 PROTOTYPE PRESENTATIONS

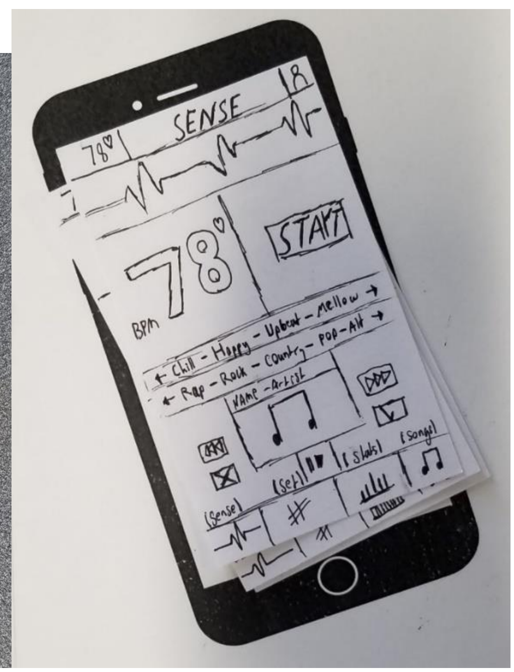


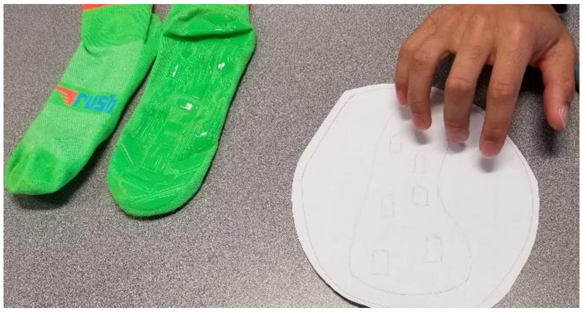


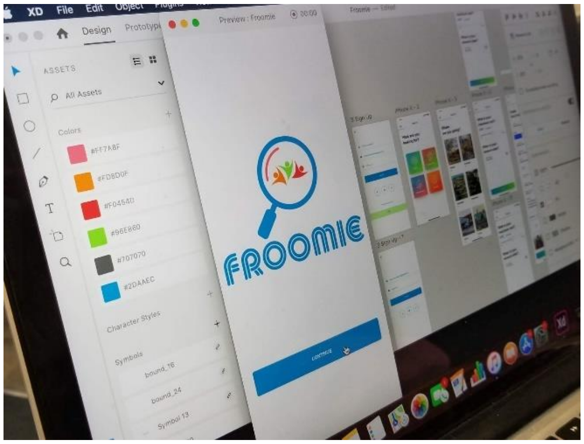


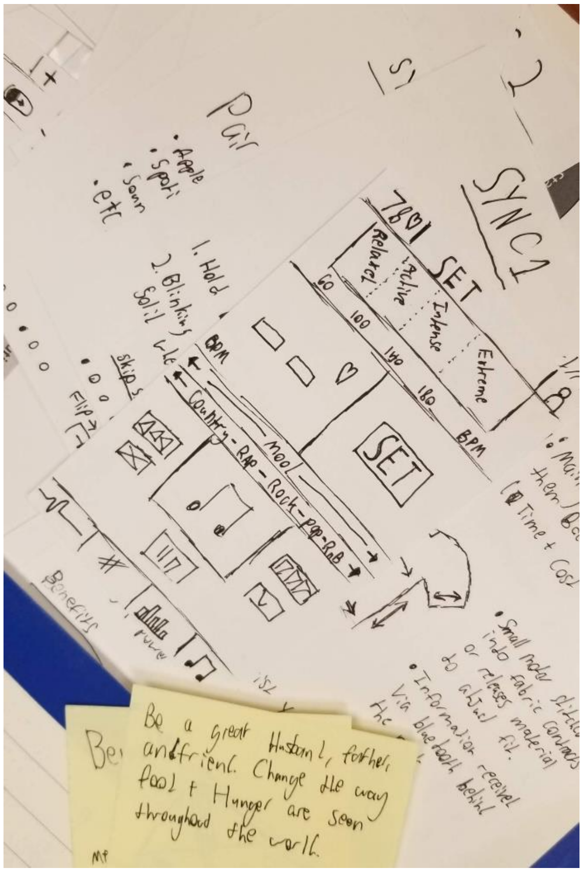

Ti-dx Prototype drawing
Solar Panel For perpetual battery power.
Derivative mode
This is a switch w/ normal mode in middle
Integral mode
Keypad to move cursor on screen
multiview screen able to scroll up & down to previous calculations.
Preview of integral mode:
Need to add: Engraving of some sort to show which mode it is in.




SENSE
START
BPM
Chill - Happy - Upbeat - Mellow
Rap - Rock - Country - Pop-Alt
NAME - Artist
(Sense)
(Set)
(Stats)
(Songs)


rush


XD
File
Edit
Object
Design
ASSETS
All Assets
Colors
Character Styles
Symbols
Preview : Froomie
FROOMIE


Be a great Husband, father, and friend. Change the way food + Hunger are seen throughout the world.
SYNC1
SET
Relaxed
Active
Intense
Extreme
BPM
Country - Rap - Rock - Pop - RnB
Pair
1. Hold
2. Blinking
Solid
Time + Cost
Benefits

APPENDIX O:

SURVEY FORMS B AND C RESULTS

The exit survey was administered as two separate handouts during the last two class of the course. Exit survey A was administered on Tuesday 11/27 and was comprised of the post instance of the design thinking traits survey

Q1. When did you first get the idea for your final project? 11/27 (survey form B)	Q2. When did you finally decide that idea would be your final project idea? 11/27 (survey form B)	Q3. Did you consider multiple ideas for your project? If so, how many? 11/27 (survey form B)
Through feedback from my peers and target audience	A month ago	2, 3
over the summer before class, in Europe	--	not really
at the beginning of the lesson	midway	not really
a few weeks in	as soon as I got it	3
About 2 weeks after we were assigned to start brainstorming for this project	After working on an extensive flowchart of how my final project (app) would be designed	I did not. I considered pretty much just the one that I did my project on.
September, in class	September	3
when we spoke about it	--	3
week 3	week 3	2
years ago	around week 3	2
I got my idea for my final project with in the first three weeks of meeting for class.	After we did the elevator pitch, and I got some feedback from my classmates.	2
3rd lesson	5th lesson	2
beginning of the class	beginning of the class	3
after about two classes	writing the design journal	2
Very late in the process. Nothing was speaking to me.	a month or so ago	3
last year	the 2nd week of class	not really
summer 2018	third week into the semester	3
after helping tutor a friend	when I completed workshop training to use 3D printer	3,4
mid-semester	when I realized how much I loved shoes	3

When I was watching a YouTube video about engines	When I felt like I could describe and make the 3D print.	I considered three different ideas.
about mid-September	a week later	3
After going to dinner with my cousin not long after class started	roughly three days after that	2,3
9/18/18	9/28/18	4
walking down a street	after talking to my grandma	3
3 weeks into class	mid-September	2

Q4. What is the name/title of your project? 11/29 (survey form C)	Q5. Who is your project for? That is, who is the target audience? 11/29 (survey form C))	*Researcher added* project type	*Researcher added* topic category
Opposed piston engines	To give an idea for future presentation. Audience is anyone interested in engines	product design	automotive engineering
Mop Socks / How Clean	children and parents with younger children	product plus mobile application	cleaning supplies
Ti-dx	STEM major students - high school or college	physical - specialized calculator	computing devices
Unwritten	families and teachers	mobile app and website	Creativity tools - fiction creation software
Music Jack Earphones headphones	My target audience is everybody who listens to content	physical - Earphone organizer	device accessories
ModStand		physical - device clamp	device accessories
Ultimate Trivia	Everyone	mobile app	educational games
PT (Personal Trainer)	Everyone that is interested in working out	mobile app	exercise
Eat Now! let's eat now! where should we eat?	Anyone! Friends, families, college students, couples, etc. who are trying to decide where to eat	mobile app	food
Froomie	pre college students	mobile app	housing
Garden Guru	Homeowners	mobile app	landscape design
The Stabilizer HQ	athletes, the elderly, individuals with arthritis, etc.	product	medical devices
Cardio DJ BPMUSIC	Everyone, but catered to music and tech lovers	mobile app	music
Ez-slide / guitar gloves	guitar players and bass players / string instruments	product design	musical equipment

FreeBoard	corporate/companies	website app	network communication technologies
ShoeMe	anyone who loves shoes - primarily age group of 15 to 25	mobile app	online retail
College Buddy	high school seniors	mobile app	productivity
Redesigning the Solar, Solar Tree	The world, large-scale and small scale	product design	solar energy design
Between Bikes	cities and campuses. Anybody who needs to get from point A to B	product with mobile application	transportation
Shuttle bus?	--	mobile app	transportation
Capacity Spot; All in one parking app	potential bus riders from apartment to UGA	mobile app	transportation
Park Buddy	people who drive/need to find a place to park	mobile app	transportation
UGA Parking app	UGA folks looking for parking	mobile app	transportation
Park Pro, SMART Park	teenagers, college students - people who are intrigued by technical advances	product with mobile application	transportation
Travel Easy	older generation who travels	mobile app	travel

S1-pre. I'm familiar with design thinking and know how to use it. (Likert 1–5) (survey form A) 8/21	S1-post. I'm familiar with design thinking and know how to use it. (Likert 1–5) (survey form C) 11/29	Q6. Please complete the following sentence beginning: "Design is…" (survey form C) 11/29
4	4	thinking outside the box
3	5	a creative process for ideas/concepts, whether they be new ideas or older ideas expanded on
--	--	--
3	3	--
2	4	the art of serving the needs and senses of the individual
3	4	anything you want it to be. Since creativity has no bounds, there is an infinite amount of ideas you can put into play. Keeping an open-mind can help you to create optimal designs and prototypes.
2	4	very helpful
5	5	solving problems, one step at a time
2	4	a marathon not a sprint. It does not come easy and takes time, but is a true growing experience
3	4	Design is figuring out a new way to go about doing something. It is using different tools to learn better more efficient ways to go about doing things.
--	4	the way we create content in a way that's beneficial to everybody with creativity and imagination
2	3	to put new ideas together and make new stuff
3	4	--
--	4	creating something that catches other's interest, whether it is useful or not, any attempt to draw attention
3	4	bringing an idea to life
2	4	--
3	4	using creativity to solve problems in innovative ways
2	5	a hybrid of physical and mental creativity
4	4	the process of making your creation
4	5	tinkering, planning, and implementing your ideas that can help you benefit your goal
3	5	a journey that visits failure, but ends at success
--	5	--
2	4	creation of something whether it is fictional or non-fictional using a creative mindset and the sky as the limit
2	4	design is a fluid, ever-changing process to change something in someone's life
1	4	structuring ideas in a creative way and layout that target users enjoy

APPENDIX P:

SUBMIT YOUR REFLECTION WEEK TWO

You can either watch the Video (10 minutes) or read the attached material. After watching or reading, please: Use less than 25 words to summarize the main idea of the video or the reading.

Reading: Kelley, D., & Kelley, T. (2013). The heart of innovation. In *Creative confidence: Unleashing the creative potential within us all* (pp. 1–11). New York: Crown Business.

Video: How to build your creative confidence | David Kelley
https://youtu.be/16p9YRF0l-g

Based on what you learned from our class and this video/book chapter, what is your take-away?

P.S. It only take you approximately 15 minutes to finish it, please submit your answer to ELC on time. Thanks.

APPENDIX Q:

JOURNEY MAP WEEK FOUR

1. Interview at least 2 of your target users. On your journey map, list the specific information of the people you interview with. Remember the journey map is the journey of your users, not your design journey. (User Information + User journey + User needs + Product functions)

2. Challenge traditional thinking and make your idea unique! Add new ideas to your journey map. Please point out the unique features of your design idea.

You can find journey map examples from this PowerPoint (Link)

APPENDIX R:

CREATIVE DESIGN GUIDELINE WEEK FOUR

Please take a photo of the guideline handout after finishing all the required steps and submit it to ELC.

Step 1: The "Magical Effect" of Your Design
Prompts:

- Who are your target audience? What magical experience you want to create for your design?

Step 2: Analyzing Traditional Thinking/Assumptions
Prompts:

- Identify the key words for your project idea, Google similar apps/products/activities.

- Case A: If you find a lot of similar ideas out there, Congratulations! There is a need there! Try to analyze those similar ideas/products and summarize the basic functions or patterns. then go to Case A.

- Case B: If our did not find any similar ideas, try use different key words and search again. if the outcome is the same, you are creating the needs for the future. Now go to Case B.

…
Case A - Challenge the traditional Thinking/Assumption
Prompts:

- Similar to the paperclip activity you did in the class, try to come up with something different with traditional design solutions. What make your design distinguish from them?

Case B - Search/Develop possible solutions
Prompts:

- You are on the journey of solving a new problem and creating a future need. What are possible solutions (tools, technology, or methods) that enable you to realize your magic and solve the problem? (you can borrow solutions from other fields)

APPENDIX S:

TOOL REPORT PROMPTS WEEK 10

Tool Report 1

- Tool reports are 2-3 minute videos where you demonstrate new tools you are learning and considering using for your project. These are tools(tool list1, tool list 2) that have been explored by previous EDIT4020 students. You can explore those tools and decide which one matches your interests and project objectives. Once you have selected a tool, describe what it's like to use the tool.

- What are you trying to accomplish with this tool? How are you using it and/or learning it? What do you like and/or dislike about this tool? Would you recommend it? For what tasks and why? In your video, show how you are using and/or exploring the tool.

- Use Screencast-O-Matic to make your video screencast. If you already use and prefer other screencasting software, it's fine to use it.

- Post your video to YouTube and submit the link to ELC drop box.

Tool Report 2 (bonus)

- Please record 1 -2 minutes long video demonstrating what tool you leaned and how that help you finish your final product.

APPENDIX T:

SPRING 2016 INITIAL CODING SCHEME FROM

Design Journal Analysis Rubric (Spring 2016 – Spring 2017)

This coding scheme was developed using grounded theory and design journal data during the Spring 2016 design of this course. These are the first codes to be identified.

Code	Abbreviation
Exploring project options	EXPP
Tool exploration	EXPT
Facing challenges/contradictions/tensions	XXX
Using design thinking methods	DT
Using creativity	CT
Existing activity system	EAT
Emerging/new activity system	NAT

The following pages provide examples of how these codes were developed using student journal data. The themes/codes developed here were used to begin development of the code structure used for the current study.

Development of coding structure Spring 2016

This process was used during the preliminary phase of this study (Spring 2016) to learn if journal entries might provide data that could inform categories supplied by activity theory and if data might reveal evidence of design thinking. The process for finding emergent themes and finding evidence for predetermined themes involved: (a) aggregating all journal entries and reading them, (b) either discovering themes (inductive) or identifying evidence for predetermined themes (deductive), and (c) consolidating the evidence from all journal entries and organizing them by theme. This process is shown below with the help of three sets of data representations: the consolidated journal entries, evidence for themes in each entry, and finally a consolidation of evidence found across all data organized by theme.

I. Design journal entries

Design Journal 1

Exploring project options

I had ***two separate ideas for my project***. Both of my ideas, however, include a mobile App useful to students in college. My first idea was to create an App which helped students study their notes. It would be both online and accessible by phone for those times you get stuck on the bus between classes. Students have a hard time learning to study all the various materials which teachers provide for them these days, especially science majors. I being a science major know that it is so easy to skim the slides a teacher gives you instead of really digging deeper into what they are giving you. Just reading the slides from say a Cellular Biology class won't help you study very well. So the App allows you to upload your slides or notes to the program and then makes you a way to study that material. The App would find words which are unfamiliar or unusual and fix them into sentences such as "Can you explain ____?" or "What does _____ mean?". In that way the students are asked to recall the information instead of just reading it and hoping they remember it. It really will test their overall understanding and information retainment. The App will also be able to extract difficult pictures and ask the user to explain or legend the image to explain the process or purpose. The App could also take sentences which are on the slides and create fill in the blanks for unusual scientific words it doesn't recognize. This way it is also like a practice exam. Testing your knowledge is the best way to study anyways.

My second idea for my project deals with the everyday struggle of dieting, dining, and budget. We all want to eat good food especially when there is such good food to be had in Athens. This App would purposely use local restaurants to help you find what you can afford, and what you can have calorie wise. You would begin the search by selecting the range of calories you would be willing to eat for lunch for example. Then you would choose the amount you would like to spend, for example under ten dollars. Then the App would select from the local restaurants or those near the user and suggest lunch items which would fit those descriptions. This way college girls like myself who are trying to diet and save money have multiple options for what they want to eat. I want to eat with my friends but I also want to be responsible about my budget and my dieting, this way I can have the best of both worlds. I think so many college girls in Athens would love this idea.

The technology for all this however, I have no idea where to even begin. I only know how to make it very appealing to audiences.

Challenges / contradictions

Design Journal 2

I believe I have decided to go ahead and pursue the mobile app (which can open up online) which helps science majors study their notes more effectively. The colors would revolve around dark calming colors to ***keep the user from feeling as stressed***. The app would have graphics which would be science related and friendly. I've been playing around with a couple different names. Anything cheesy I feel wouldn't draw a large enough crowd to the app. It needs to be cool and attractive. I started with "A-always" which I liked but then realized maybe that was too much pressure on the student, not everyone can make A's always. Then I thought "Always a way" because it sounds like there is always hope, but it was too long. So I've decided (for now) to call my app "@way" (pronounced away). I think it sounds trendy.

Exploring project options
Yes, selected project

Evidence of design thinking methods
Yes, consideration of users

Exploring tool options

The target audience is of course college science majors like myself. As I mentioned above the science oriented graphics and calming colors will attract users***. I do not yet have a plan for building it but I have perused a couple of app building sites***. I ***plan to watch a couple***

Evidence of new activity system, tool learning

tutorials on Lynda later this week after I find out the several things I want this app to be. There are so many ways it could be beneficial. I haven't narrowed it down to one. It could be much more than one but I don't want to half-do any of the functions. I want it to be able to identify uncommon words and test the user on them. I want it to be able to take the images it finds on the uploaded slides and as the user to explain it. I also want it to be able to replicate the words on a slideshow but to leave blanks so the user must identify the missing word. This will help so many people because instead of just reading the notes they are being tested. They need to explain and understanding instead of memorizing. Every science major here knows that if you just memorize the information you will never do well. This app can help them learn how to study better and facilitate more interactive learning.

Exploring tool options

I'm not sure I want to use sumopaint or the applications I have seen so far. I was really interested in building a website for it to explain it to users. The coding process was so interesting to me and I am very excited to pursue it. Step by step making some progress!

Design Journal 3

I have definitely settled on the mobile app with the accompanying website. I am sticking with the name "@ways" as I said in my last journal entry which also explained it. However, instead of intergalactic scenery to bring in science students, I decided to use a friendlier, tangible, beachy feel. Everyone is relaxed around the beach and oceans so why not begin there. I love the feel of the app and I don't mind working on it because it is something I am passionate about. In real life it would be an app which I would use. If you would like to see how I have begun to layout how I would like it to look you can look at this link. I put in really cool links on the app buttons which take you to pages which would symbolize real pages on an app

Challenge resolution

Exploring tool options

I am pretty good about doing graphic design on my own so I can make it look good but I'm having some trouble with all the technical stuff. I can design a figurative app easily but building the accompanying website is really rough. I have never built a website before seeing as how I am a Biology major, I never had a need to. ***I'm struggling with wordpress because the tutorials aren't helping for what I want***. **There isn't a real reason to have a blog or at least I**

Challenges - contradictions

Challenges - contradictions

Challenges - contradictions

haven't found a reason yet. Most of the websites I am seeing on wordpress or the themes on wordpress are for businesses and information. I would like my website to accompany my mobile app but not exceed the app. I want the uploading on the website and for it to be clean and simple. I don't want a user to have to sift through information to get what they need or to find what they need. I would like to have a simple menu with simple pages. The next thing I want to work on is to create an in-depth About page on the website. This page would go into depth about why the app is useful and why you should take the time to download and use it. It would also be cool to take some pictures of students studying to include on the page. I could even reference the website to being similar to Quizlet or StudyBlue (two school apps I use frequently). ***Once again, struggling with the tools, I can't figure Lynda out. I need to ask soon what Lynda would be good for because everything I have seen about apps have been about developing them but I am only designing one? Kinda confused on that aspect***. So far so good though!

Design Journal 4

My project is coming along nicely with marvelapp.com. I can see the finish line with this app because it keeps it simple and straight forward. Then you can play with the app like you would on a phone. It resembles an app more and more. Some of the challenges I have left is deciding how far to go into the detail on the uploading aspect of the app. Obviously without creating the app in real life it would be almost impossible to implement this considering I am only designing it. I would like to be able to upload materials to the app but considering I don't know how to develop the app I don't see it happening. I'm learning newer aspects of Marvel App. ***It's a slow process with a lot of patience required because as I learn new things on the website I mess up things I have already done***. ***The insight I have had is that maybe I need to simplify the concept of my project***. At first I thought I needed a website to help explain my app however it's a lot of work to contain nothing but information they can't actually use because they need the app, and the app wouldn't work like it would in real life. Challenges I faced were making the app usable and easy for people. I also want to make sure the app is something people want. Now without the website there has to be a way for people to upload notes to

Yes, tolerance for ambiguity Evidence of increased creative capacity

App for creative process – tol for ambi Evidence of design thinking methods

Challenges - resolution

Challenges - contradictions

their phone. I suppose I could suggest the users download dropbox or google drive. I might need to create another link to explain more about how to upload the notes. I already have an upload button and perhaps I need to fix the description to include more details. The things I love about Marvel app is how easy it is to make the app go from screen to screen by creating button areas. This way when you click on that particular space it takes you to the screen you want it to. ***I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one***. I would rather just clear the whole screen. I love the ocean theme and how it creates a comforting and creative theme. However I feel that using the same picture as the background of every screen would be so boring.

Design Journal 5

Looking back at the beginning of my project I had a lot of ideas but absolutely no clue how to execute any of them. I've never made my own website or designed an app before. I have never come across it in my major like quite a few of my classmates. There were periods of confusion for me because when we began talking about "projects" I had no idea what that was supposed to mean. What kind of a project? Was it supposed to be something for myself or everyone else? Was it supposed to be design or execution? Once I got some of those answers I couldn't seem to narrow down my scope. I wasn't sure whether to do a website or app. Finally I settled on an app. ***The feelings I feel right now are a lot different from before. First it was confusions and indecision, but now I'm kind of bored. My app is coming along nicely and as I begin to master tools I could have easily done all my ideas and not just one. I'm proud of myself for sticking to my original idea and not giving up but I want to do more now***. I, being a science major, rarely incorporated technology into my everyday studying life beyond notes online and molecular simulations. ***I went home this past weekend and began teaching my sibling how to create a blog so that she could put it on her college applications. I have no technology background and yet I was able to teach someone something. I consider that pretty cool***. Some of the most valuable things I learned were from class and how the programs we use like to walk you through so that you know how to use them. I've made mistakes along the way of designing my app but they helped me learn

Challenges - contradictions

Challenge resolution :yes

Designed an app and interactive prototype

Evidence of a new or emerging activity system

Evidence of a new or emerging activity system

Evidence of a new or emerging activity system how to use the software I was using. ***I feel much more comfortable using graphic designing programs and what now and in the future because in the process of building my app I have become more adventurous***. I have learned you can do a lot of things on your own through things such as marvelapp.com. I wish I had done a website project because wordpress is something I would've liked to use more and understand in detail. Who knows, one day someone will want me to build a website and I will know where to start. My project is coming together nicely and ***it's weird to think my peers want to hear what I have to say about the applications and tools I'm using considering I have no background with this. I love how everything is coming together***. Designing my app has been a fun look into what app designers go through. I notice things more so now about apps and what they are like than I did before.

Evidence of a new or emerging activity system

Design Journal 6

I'm finishing up final touches on my project by making it simpler and clearer. I'm also finishing up on my additional attachments on my app. This means I'm going in depth and making buttons for quizzes and flashcards. ***I had been waiting to add these features on my app because I wasn't sure how to show how this would work without having an actual user. So I have decided to use a "figurative user" and show what would happen if someone identical to me or similar to me would use the app.*** This means I would have real options to real notes on the screen however they would remain un-operational. This way when I present to the rest of the class they could see where things would be found and where the user would go to use them. I'm working out the best way to do this which is a good process because it keeps me busy. Before now I was still confused on how to present these two features (quizzes and flashcards) but now that I figured it out I can use marvelapp.com more so now than before. I thought it was cool sharing what I had learned from marvelapp.com with the rest of the class. I'm getting better at using my tools and making functional pages. It is interesting to see how my friend Kalee's app is coming along using the same software. It is cool to look back and see where my app has come from. ***I've moved from powerpoint to marvelapp and a website and app to just an app. I've narrowed my scope and gone into depth on those things***

Evidence of design thinking methods - figurative user

Exploring tool options

I've decided to focus on. I'm still having trouble putting two photos on one but I suppose that's marvel app just narrowing their abilities as well. My goal now is to try and get this website to possibly open up on my actual phone. This way when I am showing people it will actually look like a realistic app on a phone. Obviously I can't make it a real app but uploading a website link and it showing on my phone what would happen would be super cool. My hope is that when I begin presenting or showing this to my classmates they understand the purpose. Many of my classmates are not biology majors or science majors for that matter. Because of this I am nervous that they will not understand the overall purpose of my app. ***Notes again, for science majors, are often not clear or easy to study. There are no problems to work and often no projects to do like accounting and public relations majors have. Just really hope they enjoy and understand the direct need and purpose of my app***.

Tool Report 1

I have decided on one of two projects. Either the one that focuses on the study app and all that it does, or the calorie and budget food app specifically for girls in Athens. For the first option, this would obviously bring beneficial study elements to the user at ease. The second option allows users to spend time with their friends without compromising their budget or their diet. The first option provides problems, because it has a lot of technical difficulties. Those who study often will not find it as useful as those who don't study so often. The second option, would have problems with options. In order for the app to work, lots of updates would be required for when an option in downtown Athens changed their menu options.
I would need to use, for sure, a variety of app makers on the internet. I have seen several and they are all great in helping me get it together, however, none are as simple as I am thinking. Perhaps I need to think outside the box and develop a more complex app? I'm not sure yet. As far as I can see Lynda.com does cover multiple aspects of designing apps. I haven't decided on any of these yet however. I have set a goggle alert for both "Athens, Ga food" and "Athens, Ga" to get an idea of a way to present the project most marketable to users. I'm not sure if JI have found the perfect tool report yet or not but hopefully I will soon!

Tool report 2

I have been using marvelapp.com to develop my app. I'm trying to get it as close as possible to my idea that I have in my head. The thing I like about marvel is that it is simple. There are ups and downs to that because you can easily make things but they might not turn out exactly how you want them too. This is ok with me though because this app has changed multiple times over the course of this semester. I have decided not to work on a website in addition to the mobile app. I will be putting all my focus on my mobile app. Marvel App is great! It makes making your app super interactive so easy. I kind of had to play around with it as I went because it was new but some of the features they include are awesome. I love the ability to put my words on top of a translucent colored box to make them seem more important. I think this application is super neat. I haven't figured out how to put an additional picture on the picture I upload. If I could do this my buttons to go to different features of the app would look super cool. Right now they are just circles. I think I have found what I want to use for my app but I also think I could find something better if I looked some more. On the canvas part of the website I can't see the side bar completely so I have to zoom out and squint to see the options down there. This is a huge inconvenience and I wonder if it is the website or my computer.

Tool Report 3

I am developing skills for using software due to the fact I'm learning more and more about the programs I am using. It's a little bit restraining because I can think of so many ways marvelapp.com would be better and would enjoy using more. I was going to use Power Point to create my app demo but I decided to reach out into the software world and try something new. Marvel App was able to show me what my project would look like on a phone instead of myself trying to configure that part on my own. It gave me a look at how easy it would be to show everyone my project. I haven't determined if others can play on the app like I can but if they could it would be awesome in showing everyone how much like an app it would be. Using the software has helped me design my app but it has had some restrictions that are occasionally difficult to get around. It would let me open up uploaded images I already have on the website in the canvas area. The project because of this has had to become simpler. The software allows me to make the app look real but it doesn't allow me the graphic design freedom that I want. I want the freedom of Microsoft word or Power Point but the app façade of Marvel app. This way I could do whatever I wanted with whatever font or pics I wanted on my app. Also on canvas, and others have run into the same problem, you can't see the whole screen so there are certain setting you can't change. I've tried multiple times with this and to no avail had to settle for the standard settings. It's hard to add pictures to pictures. Hard to explain but on my background I wanted to put on top of it a picture of me on my about me page. It wouldn't let me do that so I ended up screen shot-ing the project, adding my pic, then screen-shotting it again to add it to canvas. This made it look so blurry and warped I had to cancel the whole addition. I haven't made as much progress as I wanted to recently because I'm struggling with a way to show how the quiz and flashcards will really look. I'm going to do some research on some apps which have this feature and see how they set this up. I'm nervous that people won't understand why I'm doing this and starting to question if I should change the name of my app. I know this is a little off-topic but just wondering what you think. I would love to show you my marvelapp.com progress the next time we are in class.

II. Supporting evidence for identified themes organized by journal entries

Tool Report 1

Themes	Evidence of theme
Exploring project options	Two project options identified
Tool exploration	Undecided and no specifics
Challenges/contradictions	
Challenge resolution	
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	

Tool Report 2

Themes	Evidence of theme
Exploring project options	Undecided and no specifics
Tool exploration	Identified a tool (Marvelapp)
Challenges/contradictions	Critical view of tool likes/dislikes some features
Challenge resolution	
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	

Tool Report 3

Themes	Evidence of theme
Exploring project options	• marvelapp over PPT as dev tool • "Marvel App was able to show me what my project would look like on a phone instead of myself trying to configure that part on my own"
Tool exploration	
Challenges/contradictions	• "The software allows me to make the app look real but it doesn't allow me the graphic design freedom that I want. I want the freedom of Microsoft word or Power Point but the app façade of Marvel app." • "It wouldn't let me do that so I ended up screen shotting the project, adding my pic, then screen-shotting it again to add it to canvas. This made it look so blurry and warped I had to cancel the whole addition." • "I'm going to do some research on some apps which have this feature and see how they set this up. I'm nervous that people won't understand why I'm doing this and starting to question if I should change the name of my app."
Challenge resolution	
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	• ability to use prototyping software to communicate design ideas • emerging ability to research tool options based upon project objectives

Design Journal 1

Themes	Evidence of theme
Exploring project options	• yes, two
Tool exploration	
Challenges/contradictions	• "The technology for all this however, I have no idea where to even begin. I only know how to make it very appealing to audiences."
Challenge resolution	
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	

Design Journal 2

Themes	Evidence of theme
Exploring project options	• yes, selected project: "I believe I have decided to go ahead and pursue the mobile app (which can open up online) which helps science majors study their notes more effectively."
Tool exploration	• "I do not yet have a plan for building it but I have perused a couple of app building sites." • "I'm not sure I want to use sumopaint or the applications I have seen so far."
Challenges/contradictions	
Challenge resolution	
Evidence of design thinking methods	• yes: consideration of users ". The colors would revolve around dark calming colors to keep the user from feeling as stressed."
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	• "I plan to watch a couple tutorials on Lynda later this week after I find out the several things I want this app to be."

Design Journal 3

Themes	Evidence of theme

• Exploring project options	• "I have definitely settled on the mobile app with the accompanying website."
• Tool exploration	
• Challenges/contradictions	• "I'm struggling with wordpress because the tutorials aren't helping for what I want. There isn't a real reason to have a blog or at least I haven't found a reason yet." • "Once again, struggling with the tools, I can't figure Lynda out. I need to ask soon what Lynda would be good for because everything I have seen about apps have been about developing them but I am only designing one? Kinda confused on that aspect." • "I am pretty good about doing graphic design on my own so I can make it look good but I'm having some trouble with all the technical stuff."
Challenge resolution	• "I have definitely settled on the mobile app with the accompanying website."
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	

Design Journal 4

Themes	Evidence of theme
Exploring project options	
Tool exploration	• marvelapp: "I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one."
Challenges/contradictions	• marvelapp: "I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one."
Challenge resolution	• "The insight I have had is that maybe I need to simplify the concept of my project."
Evidence of design thinking methods	• yes, Tolerance of ambiguity; appreciation of creative process; "It's a slow process with a lot of patience required because as I learn new things on the website I mess up things I have already done."
Evidence of increased creative capacity	• yes, Tolerance of ambiguity; appreciation of creative process; "It's a slow process with a lot of patience required because as I learn new things on the website I mess up things I have already done."
Evidence of existing activity system	
Evidence of new activity system	

Design Journal 5

Themes	Evidence of theme
Exploring project options	
Tool exploration	
Challenges/contradictions	• "Looking back at the beginning of my project I had a lot of ideas but absolutely no clue how to execute any of them. I've never made my own website or designed an app before. "
Challenge resolution	• designed an app and interactive prototype
Evidence of design thinking methods	
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	• "The feelings I feel right now are a lot different from before. First it was confusions and indecision, but now I'm kind of bored. My app is coming along nicely and as I begin to master tools I could have easily done all my ideas and not just one. I'm proud of myself for sticking to my original idea and not giving up but I want to do more now." • "I went home this past weekend and began teaching my sibling how to create a blog so that she could put it on her college applications. I have no technology background and yet I was able to teach someone something. I consider that pretty cool." • "I feel much more comfortable using graphic designing programs and what now and in the future because in the process of building my app I have become more adventurous." • "…it's weird to think my peers want to hear what I have to say about the applications and tools I'm using considering I have no background with this."

Design journal 6

Themes	Evidence of theme
Exploring project options	
Tool exploration	"I've moved from powerpoint to marvelapp and a website and app to just an app. I've narrowed my scope and gone into depth on those things I've decided to focus on."
Challenges/contradictions	"Notes again, for science majors, are often not clear or easy to study. There are no problems to work and often no projects to do like accounting and public relations majors have. Just really hope they enjoy and understand the direct need and purpose of my app."
Challenge resolution	yes, successful completion of project idea, interactive app prototype
Evidence of design thinking methods	"I had been waiting to add these features on my app because I wasn't sure how to show how this would work without having an actual user. So I have decided to use a "figurative user" and show what would happen if someone identical to me or similar to me would use the app."
Evidence of increased creative capacity	
Evidence of existing activity system	
Evidence of new activity system	

III. Supporting details for the themes

Theme	Evidence
Exploring project options	"I believe I have decided to go ahead and pursue the mobile app (which can open up online) which helps science majors study their notes more effectively." "I have definitely settled on the mobile app with the accompanying website."
Tool exploration	"I do not yet have a plan for building it but I have perused a couple of app building sites." "I'm not sure I want to use sumopaint or the applications I have seen so far."" marvelapp: "I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one." "I've moved from powerpoint to marvelapp and a website and app to just an app. I've narrowed my scope and gone into depth on those things I've decided to focus on." marvelapp over PPT as dev tool "Marvel App was able to show me what my project would look like on a phone instead of myself trying to configure that part on my own"
Challenges/contradictions	"The technology for all this however, I have no idea where to even begin. I only know how to make it very appealing to audiences." "I'm struggling with wordpress because the tutorials aren't helping for what I want. There isn't a real reason to have a blog or at least I haven't found a reason yet." "Once again, struggling with the tools, I can't figure Lynda out. I need to ask soon what Lynda would be good for because everything I have seen about apps have been about developing them but I am only designing one?

	Kinda confused on that aspect." marvelapp: "I don't like the way the canvas works though. I have to basically start over by deleting everything I have done one by one." "Looking back at the beginning of my project I had a lot of ideas but absolutely no clue how to execute any of them. I've never made my own website or designed an app before." "Notes again, for science majors, are often not clear or easy to study. There are no problems to work and often no projects to do like accounting and public relations majors have. Just really hope they enjoy and understand the direct need and purpose of my app." critical view of tool (likes some features, doesn't like others- challenged) "The software allows me to make the app look real but it doesn't allow me the graphic design freedom that I want. I want the freedom of Microsoft word or Power Point but the app façade of Marvel app." "It wouldn't let me do that so I ended up screen shot-ting the project, adding my pic, then screen-shotting it again to add it to canvas. This made it look so blurry and warped I had to cancel the whole addition." "I'm going to do some research on some apps which have this feature and see how they set this up. I'm nervous that people won't understand why I'm doing this and starting to question if I should change the name of my app."
Challenge resolution	Yes; project topic decided, tools decided, successful completion of project
Evidence of design thinking methods	yes: consideration of users ". The colors would revolve around dark calming colors to keep the user from feeling as stressed." "I had been waiting to add these features on

	my app because I wasn't sure how to show how this would work without having an actual user. So I have decided to use a "figurative user" and show what would happen if someone identical to me or similar to me would use the app."
Evidence of increased creative capacity	yes, Tolerance of ambiguity; appreciation of creative process; "It's a slow process with a lot of patience required because as I learn new things on the website I mess up things I have already done."
Evidence of existing activity system	"I am pretty good about doing graphic design on my own so I can make it look good but I'm having some trouble with all the technical stuff."
Evidence of new activity system	"I plan to watch a couple tutorials on Lynda later this week after I find out the several things I want this app to be." "The feelings I feel right now are a lot different from before. First it was confusions and indecision, but now I'm kind of bored. My app is coming along nicely and as I begin to master tools I could have easily done all my ideas and not just one. I'm proud of myself for sticking to my original idea and not giving up but I want to do more now." "I went home this past weekend and began teaching my sibling how to create a blog so that she could put it on her college applications. I have no technology background and yet I was able to teach someone something. I consider that pretty cool." "I feel much more comfortable using graphic designing programs and what now and in the future because in the process of building my app I have become more adventurous." "…it's weird to think my peers want to hear what I have to say about the applications and tools I'm using considering I have no

background with this."

ability to use prototyping software to communicate design ideas - emerging ability to research tool options based upon project objectives

APPENDIX U:

CODE FREQUENCY, SPREAD, RANGE, CHANGE, AND MEDIAN

Code	Journals		Interviews
	Total frequency, spread[a], range, median	Frequency per journal I, II, III, IV, overall change	Total frequency, spread, range, median
Contradictions	112, 100%, 1-8, 4	2, 28, 35, 47, +45	25, 100%, 1-10, 5
Tool exploration	81, 92%, 1-8, 3	0, 21, 35, 25, +25	35, 100%, 4-10, 7
Prototyping	73, 92%, 1-7, 3	1, 29, 32, 11, +10	26, 100%, 2-11, 4
Exploring project options	63, 96%, 1-6, 2	43, 8, 3, 9, -34	23, 80%, 2-9, 5
Outcome	59, 96%, 1-5, 2	1, 0, 1, 57, +56	17, 100%, 3-4, 3
Empathy - human-centeredness	52, 100%, 1-5, 2	31, 6, 10, 5, -26	22, 80%, 3-9, 3
Community	42, 72%, 1-6, 2	5, 8, 12, 17, +12	62, 100%, 6-17, 14
Feedback seeking	36, 72%, 1-4, 1	0, 3, 20, 13, +13	33, 100%, 2-13, 6
Problem finding	33, 80%, 1-3, 1	25, 4, 1, 3, -22	14, 100%, 1-5, 2
Creative agency	24, 40%, 1-6, 0	0, 0, 6, 18, +18	8, 80%, 1-3, 2
Emerging-new activity system	18, 32%, 1-5, 0	0, 0, 5, 13, +13	10, 80%, 1-4, 2
Motivation	18, 44%, 1-3, 0	11, 1, 0, 6, -5	19, 60%, 3-11, 3
Locating and using resources	17, 48%, 1-2, 0	0, 8, 5, 4, +4	10, 80%, 1-4, 2
Convergent thinking - evaluation	16, 40%, 1-4, 0	3, 2, 3, 8, +5	5, 80%, 1-2, 1
Tolerance of ambiguity	14, 36%, 1-4, 0	0, 2, 1, 11, +11	8, 80%, 1-3, 2
Divergent thinking - ideation	13, 32%, 1-3, 0	7, 1, 1, 4, -3	8, 80%, 1-4, 1
Optimism	13, 40%, 1-3, 0	4, 1, 0, 8, +4	1, 20%, 1-1, 0
Playful attitude fun/excitement	11, 32%, 1-2, 0	2, 0, 1, 8, +6	11, 100%, 1-4, 2
Existing activity system	8, 28%, 1-2, 0	4, 2, 0, 2, -2	11, 40%, 3-8, 0
Collaboration	7, 20%, 1-2, 0	1, 0, 2, 4, +3	9, 60%, 2-4, 2
Feelings of surprise	7, 28%, 1-1, 0	1, 0, 0, 6, +5	2, 40%, 1-1, 0
Time management	7, 28%, 1-1, 0	0, 0, 3, 4, +4	2, 40%, 1-1, 0
Subject	5, 16%, 1-2, 0	4, 1, 0, 0, -4	18, 100%, 1-8, 2
Division of labor	4, 16%, 1-1, 0	0, 0, 0, 4, +4	10, 100%, 1-4, 1
Integrative thinking	3, 12%, 1-1, 0	0, 1, 0, 2, +2	2, 40%, 1-1, 0
Object	3, 12%, 1-1, 0	1, 0, 1, 1, 0	3, 40%, 1-2, 0
Questioning	2, 8%, 1-1, 0	0, 0, 2, 0, 0	9, 60%, 1-6, 1
Co-evolution of problem-solution	1, 4%, 1-1, 0	0, 1, 0, 0, 0	4, 40%, 1-3, 0
Framing	0, 0%, 0-0, 0	0, 0, 0, 0, 0	0, 0%, 0-0, 0
Operations	0, 0%, 0-0, 0	0, 0, 0, 0, 0	3, 40%, 1-2, 0
Psychological safety	0, 0%, 0-0, 0	0, 0, 0, 0, 0	5, 60%, 1-3, 1
Rules	0, 0%, 0-0, 0	0, 0, 0, 0, 0	3, 40%, 1-2, 0
Abductive logic	0, 0%, 0-0, 0	0, 0, 0, 0, 0	1, 20%, 1-1, 0

Note: Parent codes omitted from rankings: Activity theory, Creative design ability, Experimentalism, Project management, Survey factors

[a] Percentage of participants who were coded for each code

APPENDIX V:

JOURNAL CODE RANKINGS

Code	Frequency	Spread[a]	Code category
Contradictions	112	100%	organizational
Tool exploration	81	92%	action
Prototyping	73	92%	action
Exploring project options	63	96%	action
Outcome	59	96%	organizational
Empathy - human-centeredness	52	100%	affect
Community	42	72%	action
Feedback seeking	36	72%	organizational
Problem finding	33	80%	action
Creative agency	24	40%	affect
Motivation	18	44%	affect
Emerging-new activity system	18	32%	organizational
Locating and using resources	17	48%	action
Convergent thinking - evaluation	16	40%	action
Tolerance of ambiguity	14	36%	action
Divergent thinking - ideation	13	32%	action
Optimism	13	40%	organizational
Playful attitude fun/excitement	11	32%	affect
Existing activity system	8	28%	organizational
Collaboration	7	20%	organizational
Feelings of surprise	7	28%	affect
Time management	7	28%	action
Subject	5	16%	organizational
Division of labor	4	16%	organizational
Object	3	12%	organizational
Integrative thinking	3	12%	organizational
Project management	3	0%	organizational
Questioning	2	8%	action
Co-evolution of problem-solution	1	4%	action
Psychological safety	0	0%	organizational
Operations	0	0%	organizational
Rules	0	0%	organizational
Abductive logic	0	0%	action
Framing	0	0%	organizational

Note: Parent codes omitted from rankings: Activity theory, Creative design ability, Experimentalism, Survey factors.

[a] Percentage of participants who were coded for each code

APPENDIX W:

JOURNAL CODE TIME SERIES

Code	All[a]	I[a]	II[a]	III[a]	IV[a]	Change[b]
Contradictions	112	2	28	35	47	45
Tool exploration	81	0	21	35	25	25
Prototyping	73	1	29	32	11	10
Exploring project options	63	43	8	3	9	-34
Outcome	59	1	0	1	57	56
Empathy - human-centeredness	52	31	6	10	5	-26
Community	42	5	8	12	17	12
Feedback seeking	36	0	3	20	13	13
Problem finding	33	25	4	1	3	-22
Creative agency	24	0	0	6	18	18
Emerging-new activity system	18	0	0	5	13	13
Motivation	18	11	1	0	6	-5
Locating and using resources	17	0	8	5	4	4
Convergent thinking - evaluation	16	3	2	3	8	5
Tolerance of ambiguity	14	0	2	1	11	11
Divergent thinking - ideation	13	7	1	1	4	-3
Optimism	13	4	1	0	8	4
Playful attitude fun/excitement	11	2	0	1	8	6
Existing activity system	8	4	2	0	2	-2
Collaboration	7	1	0	2	4	3
Feelings of surprise	7	1	0	0	6	5
Time management	7	0	0	3	4	4
Subject	5	4	1	0	0	-4
Division of labor	4	0	0	0	4	4
Integrative thinking	3	0	1	0	2	2
Object	3	1	0	1	1	0
Project management	3	0	1	1	1	1
Questioning	2	0	0	2	0	0
Co-evolution of problem-solution	1	0	1	0	0	0
Abductive logic	0	0	0	0	0	0
Framing	0	0	0	0	0	0
Operations	0	0	0	0	0	0
Psychological safety	0	0	0	0	0	0
Rules	0	0	0	0	0	0

Note: Parent codes omitted from rankings: Activity theory, Creative design ability, Experimentalism, Survey factors
[a]Code frequency counts for all journals and journals I, II, III, and IV, respectively
[b]Difference in code frequency count from journal I to journal IV

APPENDIX X:

INTERVIEW CODE RANKINGS

Code	Frequency	Spread	Code category
Community	62	100%	action
Tool exploration	35	100%	action
Feedback seeking	33	100%	organizational
Prototyping	26	100%	action
Contradictions	25	100%	organizational
Exploring project options	23	80%	action
Empathy - human-centeredness	22	80%	affect
Motivation	19	60%	affect
Subject	18	100%	organizational
Outcome	17	100%	organizational
Problem finding	14	100%	action
Existing activity system	11	40%	organizational
Playful attitude fun/excitement	11	100%	affect
Division of labor	10	100%	organizational
Emerging-new activity system	10	80%	organizational
Locating and using resources	10	80%	action
Collaboration	9	60%	organizational
Questioning	9	60%	action
Creative agency	8	80%	affect
Divergent thinking - ideation	8	80%	action
Tolerance of ambiguity	8	80%	action
Convergent thinking - evaluation	5	80%	action
Psychological safety	5	60%	organizational
Co-evolution of problem-solution	4	40%	action
Object	3	40%	organizational
Operations	3	40%	organizational
Rules	3	40%	organizational
Feelings of surprise	2	40%	affect
Integrative thinking	2	40%	organizational
Time management	2	40%	action
Optimism	1	20%	organizational
Abductive logic	0	20%	action
Framing	0	0%	action

Note: Parent codes omitted from rankings: Activity theory, Creative design ability, Experimentalism, Project management, Survey factors

[a] Percentage of participants who were coded for each code

APPENDIX Y:

PROJECT DESIGN CREATIVITY SURVEY

Factor	Item ID	Survey item	Item repetition	Measurement scale
Tool exploration				
	T1	I am good with using software design tools.	repeated measure	Likert response scale 0-10
	T2	I explored a lot of different tools during my project work.	single measure	Likert response scale 0-10
	T3	How many software tools did consider for your project work?	single measure	ratio scale
	T4	How many software tools did use for your project work?	single measure	ratio scale
	T5	The tools I used for my project work were useful to me.	single measure	Likert response scale 0-10
	T6	Estimate how much time you spent learning how to use software for your project work.	single measure	ratio scale
	T7	Estimate how much time you spent actively using software tools work on your project.	single measure	ratio scale
	T8	I would use the same tools again that I used for my project work in this course.	single measure	Likert response scale 0-10
	T9	The tools I used for my project work helped to improve the creativity of my design ideas.	single measure	Likert response scale 0-10
Prototyping				
	P1	Prototypes helped my design process.	repeated measure	Likert response scale 0-10
	P2	How many different kinds of prototypes did you make during you course work? (The categories are, sketches, mind maps, physical models, paper prototypes, digital prototypes, and others…)	single measure	ratio scale
	P3	Estimate the number of prototypes you made during your course work.	single measure	ratio scale
	P4	Prototypes helped me think of new ideas.	single measure	Likert response scale 0-10

	P5	Prototypes helped me communicate my ideas to others.	single measure	Likert response scale 0-10
	P6	My prototypes looked a lot like the finished product I envisioned.	single measure	Likert response scale 0-10
	P7	Prototypes helped me improve my design.	single measure	Likert response scale 0-10
	P8	My prototypes were not realistic enough for me to get meaningful feedback.	single measure	Likert response scale 0-10
	P9	The feedback I got from my prototypes helped me improve my design ideas.	single measure	Likert response scale 0-10
Creative Agency				
	CA1	I have the potential to be creative.	repeated measure	Likert response scale 0-10
	CA2	I can be creative in my project work.	repeated measure	Likert response scale 0-10
	CA3	I learned to be creative during this course.	single measure	Likert response scale 0-10
	CA4	I think I will develop my creative skills more in the future.	single measure	Likert response scale 0-10
	CA5	In general, other people are creative or can learn to be creative.	single measure	Likert response scale 0-10
	CA6	People in this course helped me improve the creativity of my design ideas and prototypes.	single measure	Likert response scale 0-10
	CA7	My experience in this course helped me to be more creative.	single measure	Likert response scale 0-10
Motivation				
	M1	I am engaged with my project work at this time.	repeated measure	Likert response scale 0-10
	M2	I look forward to learning and using design tools.	repeated measure	Likert response scale 0-10
	M3	I look forward to prototyping my design ideas	repeated measure	Likert response scale 0-10
	M4	I look forward to interacting with others in the class	repeated measure	Likert response scale 0-10
	M5	In this course I felt free to explore and pursue my ideas.	single measure	Likert response scale 0-10
	M6	I didn't have many ideas for my project.	single measure	Likert response scale 0-10
Community				
	C1	People in this course helped me make progress with my project work.	repeated measure	Likert response scale 0-10
	C2	The instructor(s) in the course helped me make progress with my project work	repeated measure	Likert response scale 0-10

	C3	people in this course helped me learn more about design tools	single measure	Likert response scale 0-10
	C4	people in this course helped me improve my design ideas and prototypes	single measure	Likert response scale 0-10
	C5	I was comfortable sharing my design ideas with people in this course.	single measure	Likert response scale 0-10
	C6	It was easy to share creative ideas with people in this course.	single measure	Likert response scale 0-10
	C7	Presenting my ideas to others was helpful.	single measure	Likert response scale 0-10

APPENDIX Z:

STUDENT OUTCOMES JOURNAL EVIDENCE

The following snippets from the last set of journal entries were coded as outcomes and represent what participants said they learned from the course.

I see myself more as a designer since I did not consider myself one before.

Some of the most valuable things I have learned is that your creativity does not stay the same. You can be as creative as you want throughout life.

In the future, I can use these same tools or find better ones to resolve a problem I might have.

I had a very small idea that turned into something that could be realistically possible in the engineering world. I had originally thought that my idea was out of the scope for this class, but it has proven to me that a lot can be achieved in a short amount of time.

One of the most valuable things I learned in this class is that when creating any product, service, or application, there should be a thought process set that accompanies the general public's desires.

This class also taught me about many websites and tools that one can use to create projects and products. The 3D printing lab is one of those examples – I would not have desired to go to Makerspace for any reason until now. It is actually one of the most helpful and useful places at UGA for free!

Early in the semester when we were shown a prototype of an application from a student's final project, I was intimidated. I thought that it looked impossible to make and difficult to learn how to use different tools to even begin designing. I was stressed that I could not perform adequately because I am not the best at technology. However, as the semester went on, my views on my own creativity and confidence changed drastically. After learning about many different apps and websites that could assist me on my final prototype, I began to relax.

Additionally, it helped to get insight from my peers who were going through the same thing I was. Together, we figured out how to navigate different platforms for the future.

One of the most valuable things I learned during this process was creative confidence. In order to perform to the best of my ability, I need to believe in my creativity skills to achieve more on my ideas. Also, although my ideas may fail over and over again, I need to maintain confidence that my creations can work in the future.

For instance, when I first started using Adobe XD, I was intimidated and confused on how to use this application. After fiddling with it for a little bit, I became frustrated because I kept messing up what I was doing and could not advance further. However, after practicing for a while and watching tutorials, I started to get the hang of it and it became more fun. If I choose to design an application in the future, I will definitely use Adobe XD to create my prototype. I will be confident in my abilities while keeping an open mind about design and the world around me.

There were very few periods of confusion, however when they did arise the main issue was technical issues with creating a prototype – the conceptualization for the app was always clear, and with [instructor's] help I was able to add even more features to the app to make it useful to users – being that I had never used applications such as Marvel to visualize prototypes, this was a learning process.

One of the most valuable things that I learned in this process was that the input from others can be very useful as it was throughout this process and can actually aid in creating an idea even better than the original.

Throughout they journey of creating a project, I went from not knowing which project to choose, to slowly creating a project with slight variations from products already made, to creating a final product design using the 3D printer.

Overall throughout the experience I learned how to foster my creative side when it comes to figuring out alternative uses for products and how to make something your own. By using the makerspace 3D printer to print my product, I am now aware of the capabilities of a 3D printer and also other websites and programs used during class.

Looking back at where I started on my project, I'm proud of how far I have come with it. From just the beginning of an idea in my head to something real is incredible.

The biggest thing I'll take away from this project though, is the experience of not being told what to do every step of the way. That was a first for me. The open-ended idea of the project can be very challenging because every single decision about it falls to me. I've definitely grown to like that though. It introduces you to a whole new way of thinking.

I've definitely learned a lot in this class, more than I ever thought I would to be honest.

I really enjoyed XD and I really think I could invest in this app and create something more serious down the road.

The most valuable things I've learned is that anyone can be creative and that you can increase your creativity levels. I think that I'll use technology more in my daily life. No matter what I'm trying to do, I can figure out a tool that can either A) help me learn what I'm doing, or B) Use the tool to actual do it for me.

In the future I might try to use more technology in my work because I feel it can help you communicate with others more effectively.

The idea seemed simple to create, yet little did I realize this was a much bigger project than anticipated. This project had many more parts than just hardware. In order to complete this project in its entirety, programming, circuit work and much more is a necessity to have a working product. This caused a massive amount of stress as I first expected to complete a working prototype for the showcase. That is when I decided to complete a physical copy of the calculator as my final project rather than a working one.

The most valuable lesson learned from the project is that there is a designer in everyone. I am a mechanical engineer with very little design experience and this project made me realize I had the capability to design whatever comes to thought. This project experience will affect the way I use technology in the future to show a little more gratitude towards this technology. I can say I now appreciate the tools used in the making of this project a little more as well.

I learned that designing an app takes a large amount of work and that the lens of the app designer has to carefully cater to the needs and wants of the user. I also learned that because of this, the challenge of having to do the same thing repeatedly, due to the fact that an array of different possibilities can arise for any user when journeying through the app. This experience has shaped me to think more creatively and to be more aware of the perspective of the user and their different needs.

Overall, this experience was a beneficial one and allowed me to grow in ways that I did not imagine at the start.

These ideas would lead me to further progress my project into its final iteration, the solar tree. This “tree” would support multiple panels in an attempt to collect the heat from each one in order to increase the solar heat output through a steam engine.

During this project, I learned that new issues can arise in every step of a design. I also learned that sometimes testing an idea isn’t as straightforward as it appears to be, initially. Working on this project may benefit me in the years to come because in my courses for my engineering degree, I was usually placed in design groups to complete projects.

I think the time I experienced the most stress is when we started using Adobe XD. It was a tricky program to learn, but once I did getting through this project was a breeze. I learned throughout this entire project that I am a creative person. Starting this class, I never really saw myself as a creative. I always saw myself as someone who was just good at numbers. Making this app, among all the other activities in this course, have really helped me shape myself into a creative individual which I am so grateful for.

I will use the more creative side of my brain from here on out especially in my work and everyday life.

Developing my product over these past weeks as truly been a journey and a fun learning experience.

I learned how to use tools that I would not have ever imagined being proficient with.

Building this project was a great experience, I now have more confidence not only in my creative ability but also the ability of others because everyone can be creative it just depends on how you look at things. This class taught me how helpful simply changing my perception can be.

At the beginning, all I knew that I wanted to create was a travel app. But now, I have a working app for an older generation of travelers with a wide variety of features.

I have learned many valuable tools through this process, especially new technology tools like Pixlr and Adobe XD. These tools will definitely help me in the future throughout my career and with more projects.

Refining my ideas and the design process is something I will do a lot in my career as a Digital Marketer, so this project will be extremely helpful.

I couldn't come out a good idea to keep the target users to stay with the app beside physical reward.

I found that windows system is not friendly to most design tools.

The most valuable thing that I learned from this class is that everyone can become a designer. As long as we are able to break the original assumption, we may come out some good ideas that can be used in our daily life. In the future, I will think of all possible solution and choose the best one to implement it.

When I had completed my final project, I wound up being really proud of my work.

Overall, the biggest thing I learned from the class was how important it is to follow a process when it comes to design. As someone said to me later in the semester, "you can't build the 20th floor on top of the 1st".

I think in the future, knowing how to solve complicated problems in this fashion will allow me to overcome large-scale problems through any means necessary. The class wasn't what I was expecting when I signed up, but it was very fun, and I've come away with skills beyond classroom teaching.

Some of the most valuable things I learned throughout this semester working on my project were time management, not shooting down an idea I thought was crazy, and lots of creative confidence.

Before entering this course, I would not think of myself as one who is creative. However, over these past couple of months my mind has changed the way it views things and I am proud of it.

I think that this project was a great steppingstone for my future. It allowed me to think in ways I will have to everyday for the rest of my life. It allowed me to see the bigger picture of medicine and not just understand the

black and white. I can now confidently say I have a creative mind and there is no stopping my progress with anything in the future.
THANK YOU [instructor].

The entire journey, from the beginning up to now, has been a very unpredictable road. There were many situations where I did not know where this project would end up. The uncertainty had me worried a lot in the beginning of the semester, however, as I spent more time developing ideas and concepts inside that uncertainty, I built more confidence.

The main challenge I would say that was difficult and important was thinking of a problem we wanted to solve. When you ask a broad generic question like “What kind of problem do you see around you?” it is very confusing on what to think about. Many of the students were afraid to talk because they were not confident in their own thoughts and ideas. The idea conception is where the first and hardest challenge came. I believe it is the most important one because it is at this phase, that we decide what to work on for the rest of the semester.

I learned that creativity is just like any other skills, it can be refined and improved through practice and experience. Also, creativity does not come to you when everything is comfortable and working perfectly satisfied. Creativity blooms when you run into an issue or problem, it is when you ask why this can’t be avoided or be changed.

My attitude towards selecting projects changed after this class. I used to be the type where if I predict that a project will face almost impossible challenge, I would not bother to investigate it. Now, I am little excited to take on those difficult challenges because it will push me to be more creative.

To move past these feelings of stress, I had to compromise a little with myself. I had to decide what I could fix with my current abilities and what I couldn’t. I began to accept my design for what I could make it and didn’t allow myself to consider what it would be like if someone with my experience had done this instead. After all of this, I really began to feel proud about my creation. I had created something—something people wanted to use. That feeling of pride far outweighed any of my previous feelings of stress.

I learned that I have the ability to succeed at anything I attempt because as I’ve learned through design, the attempt itself is a success because it means you did something new. Everything I create doesn’t have to be perfect; in fact, everything I create shouldn’t be perfect. If it was, I would never learn how to move past it.

The first issue is that the platform I used to make my digital prototype was Adobe XD. It is relatively new and one feature that I think should be implemented is an auto save function. I say this because I lost my final digital prototype not once, but twice. I finished it the first time and saved the file, however it was later discovered that the file had been damaged upon saving it. This caused me some trouble within the timeframe of the day we were supposed to present, and I was left scrambling trying to finish my project, which I believe still turned out well.

Another issue with XD is that it is difficult to make your project seem unique. There are several templates that are downloadable, however, like I saw with my original prototype, it makes it easy to just use these templates and then you lose touch with your original idea that you began with. Overall, I would say that Adobe XD is a powerful tool that, when completely mastered, gives its user the ability to create anything that they put their mind to. This issue is that mastering this platform takes a good amount of time and practice.

It was a struggle to find out not only what I wanted to do with my idea, but what my potential users would like to feel and experience while using it. It was quite difficult to fully understand the needs of others but through communication and a variety of interview type questions I was able to do just that.

The most valuable thing that I learned in this class is that everybody has their own uniqueness, and everyone can be a creative designer. Coming into this class, I believed that I had no creativity at all. However, through exercises and looking at [instructor's] magic tricks, I was able to understand some of the steps and practice my brain to thing in a creative way.

Building this project has motivated me to continue with it as I move forward. If I can constantly keep improving this and maybe even receive help to code and actual app, I might one day be able to pitch this idea to a group of investors.

I think I have made a lot of progress throughout the duration of this course. I have a new perspective on what design thinking really is. I have learned to never fear what others may think and to always trust myself and design what feels right to me.

Throughout the design process of my project I was able to learn about several new tools that I did not know were out there. Tools that I will most certainly use on future project of my own. After going through the design process myself I think I will have more of an appreciation for others ideas. Realizing just how hard it is to bring an idea to life. Overall, I think this was a great experience and one that I not only enjoyed but also learned a lot from.

One thing that I found very valuable from this assignment was that even though every single person in the class was given the same assignment we all used our previous life experiences and interests to create different project ideas. I found this valuable because it really showed how collaborating with others can lead to more refined ideas.