

Designing for 'Seeing Across Projects' Based Learning

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Abstract

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Human Centered Design & Engineering

Design thinking is an important skill in engineering practice, but it is difficult to teach and learn. The primary means of teaching design is by engaging students in project-based design experiences. In addition to supporting students in having design experiences, there is a need to help students get more out of the design experience they are already having. This gap presents a design research opportunity for which there are many directions to explore.

The variation theory of learning posits that people learn through exposure to certain patterns of variance and invariance across instances of a concept. However, there are few systematic curricular efforts to help students learn by seeing across collections of personal or community design experiences. This work explores the design research problem and opportunity of ***“how might we design environments that support learning from seeing across individual design experiences?”***

A three-phase design research approach was used. First, the iterative design of several learning environments and activities over four years was framed as a series of research through design (RtD) inquiries that all addressed the same broad design research question. This resulted in over fifty learning activities (RtD artifacts) named 'seeing across projects (SAP)' activities.

Second, these artifacts were synthesized using the annotated portfolio methodology. Two Annotated portfolios were created, the first focused on breadth, and the second focused on depth. Variation theory was used as an analytical lens to provide insights on what was made possible to learn in the enacted learning environment annotations. These two portfolios resulted in a model that describes the five key elements of the analyzed SAP activities. This also resulted in the identification of three key properties of SAP activities (content, source, and selection), their values, and some potential implications they have for learning and the feasibility of implementation.

Finally, the model resulting from the annotated portfolio was aligned with the key principles of the variation theory of learning to create a framework for designing SAP activities grounded in a learning theory.

Overall, the results of this work are the proposal and initial investigation of a new, but complementary, pedagogical direction for engineering design education called 'seeing across projects' based learning.

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Chapter 1: Introduction

Design thinking is an important skill in engineering, but it is difficult to teach and learn [7]. One of the primary means of teaching design is through project-based learning (PBL) courses [1, 7]. PBL is extensively studied in engineering education research. While design courses with PBL components have many good outcomes, there is still a need for further innovation in how we teach design.

Engineering education began with practice-based apprenticeship models, but by the mid-twentieth century, engineering education curricula were predominately filled with engineering sciences. Critiques that students were not prepared for the workforce and pressure for the United States to remain globally competitive forced returned attention to increasing design practice in the curriculum.

Over the past 30 years, the number of PBL courses in engineering education has increased [5, 8]. The predominant curricular model for teaching design in accredited institutions is through a project-based design course in the first year (called first-year design or cornerstone), followed by a culminating capstone design experience in the final year [5, 7]. There have been efforts to eliminate the gap in design practice between the first and final year, but a constant struggle of what to include in a tight and over-packed curriculum is one of the enduring questions in the history of engineering education [5].

In addition to the increase in design experiences in the higher education curriculum, design

experiences have been added to the k-12 curriculum [6, 11]. The growth of the maker-movement and academic maker spaces has increased access to informal project-based design learning experiences [2, 14].

Herbert Simon famously states, “To design is to devise courses of action aimed at changing existing situations into preferred ones.” If we take this broad view of design, students already engage in many design experiences throughout their lifetime, both within and outside formal engineering education. While there are still calls for adding more design coursework to the engineering curriculum in higher education [13], it is difficult to find space. An under-explored avenue for improving design education is to focus on how we might help students get more out of the design experiences they are already having.

Rather than engaging learners in more design experiences, how can we help them get more out of the design experiences they are already having?

The variation theory of learning [12] provides a lens through which to leverage this opportunity. Variation theory posits that people learn by experiencing similarities and differences across instances of a phenomenon. In current models of PBL, learners focus on engaging in one design experience. While they might be exposed to other design instances through critiques or final presentations, there are few systematic curricular

efforts to help students learn by seeing across collections of personal or community design experiences.

Thus, in this dissertation, I ask the following design research question:

How might we design environments that support learning from seeing across individual design experiences?

Design as Research Method

Many authors argue that there is no universally preferable research method but that instead, the method should be matched to the research question or goal [3]. This work aims to explore the question of “what could be” rather than “what is.” Therefore, a design research methodology such as Research through Design (RtD) is appropriate [17].

Research through Design (RtD) is a methodology used in the field of Human-Computer Interaction (HCI). It leverages the methods of design to surface knowledge that can only be generated through the creation of a new artifact. RtD can be seen as a response to the challenge that “things proceed theory” [16]. A classic example of this in HCI is that the computer mouse needed to be invented before it could be shown to be a better design than prior computer interface devices. A similar challenge exists in engineering education research - innovative learning environments must be designed before we can prove them to be good learning environments. Though RtD is not yet commonly used in the field of engineering education, the method provides an opportunity to surface new kinds of knowledge important to the field.

Approach

In this dissertation, I introduce the concept of ‘seeing across projects (SAP)’ activities as a potential solution to the design research goal of designing for ‘seeing across projects’ based learning. A three-stage RtD process was utilized (see Chapter 4).

First, the iterative design of several learning environments and activities over four years was framed as a series of RtD inquiries that all addressed the same broad design research question: How might we design environments that support learning from seeing across individual design experiences? This resulted in over fifty RtD “artifacts” framed at the scale of learning activities. Second, these artifacts were synthesized using the annotated portfolio [4, 9, 10] methodology. Two annotated portfolios were created. The first focused on breadth, and the second focused on depth. Variation theory was used as an analytical lens to drive annotations. Finally, the model resulting from the annotated portfolio was aligned with the key principles of the variation theory of learning to create a framework for designing ‘seeing across projects’ based learning activities.

Contributions

This research provides design, empirical, theoretical, and methodological contributions [15] relevant to the fields of engineering education research, education practice, and human-computer interaction.

First, this work provides a design (artifact) contribution through the generation of multiple RtD prototypes of learning environments. As little prior research has been done in the area of designing for learning from seeing across individual design experiences, this work will introduce a new area of engineering design education research for consideration. These RtD artifacts inspire new kinds of learning environments and future research. A model for ‘seeing across projects’ activities is shared in Chapter 5, along with detailed descriptions of two ‘seeing across projects’ activities (RtD artifacts).

Second, this work provides an empirical contribution in the form of conceptual themes that surfaced from the annotated portfolio analysis. These insights outline three key features of Seeing Across Projects Activities, note variations in these features, and articulate potential implications of the feature on learning and feasibility. These findings are shared in Chapter 6.

Third, this work provides a theoretical contribution in the form of a framework that aligns the Variation

Theory of learning to project-based learning design teaching pedagogy.

Finally, this work provides a methodological contribution by presenting a case study of the use of RtD in the engineering education context (the design of learning environments).

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Chapter 2: Design Education and Variation Theory

Design in Engineering Education

History and Current State

Design is a central aspect of engineering. Engineers grapple with ill-structured problems containing multiple solutions [21, 37]. Wilczynski states that “To engineer is to design” [39], and Dym refers to the purpose of engineering education as “to graduate engineers who can design” [17]. Training competent designers is essential to American competitiveness [39]. However, its complexity makes design challenging to teach and learn [17].

Higher Education

The topic of design has always been part of the engineering curriculum, but how much focus and how to integrate it has changed over time. A matter of great debate throughout the history of engineering education is the balance between design practice and engineering sciences [11]. This history is often described as the swinging of a pendulum, back and forth between a focus in engineering education on engineering practice and analytical grounding in math and science. Engineering education began with engineers trained through hands-on apprenticeships in the workplace. By the end of the 19th century, the desire to obtain the prestige of a profession and the emergence of technologies that required grounding in basic science for development and operation shifted engineering education from the workplace into the classroom.

By the end of the twentieth century, the engineering education curriculum was primarily engineering science. Perceived threats to American competitiveness and complaints that engineers lacked problem-solving skills led to curricular reform, swinging the pendulum back towards hands-on design experiences [11, 19]. This reform has resulted in the use of project-based learning (PBL) pedagogical models to evolve students in engineering design projects, most often through a first-year design course at the beginning of an engineering program and a senior capstone design course in their final year [11, 17].

The senior capstone design course is a staple of design education in higher education. Early capstone courses began in the 1960s [19]. Accreditation changes in the 90s led to increased adoption of the senior capstone design course.

In the early years, basic science and engineering sciences can be seen as “obstacles to overcome before real engineering education can begin” [34]. As part of the shift toward greater emphasis on design, first-year design courses (also called cornerstone courses) have been implemented in many engineering education institutions [17, 19, 36]. These first-year design courses use project-based learning (PBL) pedagogy to either focus solely on a design project or incorporate a team-based project with other material [17]. First-year design courses can positively influence students’ development and retention [19, 34]. A survey of 197 respondents in 2010 found that 92% of respondents were aware of first-year programs,

while 65% of them had implemented them in their programs [10]. There is wide variation in how first-year design courses are taught compared to the instructional uniformity in engineering science subjects [6].

Design is a skill that must be practiced over time [34]. However, the “bookend” curricular practice of first-year design courses and a senior capstone design leaves a “desert of design” during the sophomore and junior years [19]. This gap can result in the deterioration of technical and professional skills [24], leading to efforts and recommendations to integrate design across the curriculum [9, 18, 21, 24, 34, 39]. Seely notes that one of the constant challenges over the history of engineering education is “what to include in tight curricula”[11]. Integrating across engineering programs has been challenging, and there are still calls for more design experiences.

K-12 and Informal learning

In addition to the increase in design experiences in the higher education curriculum, design experiences have been added to the K-12 curriculum [13, 23]. For example, the Engineering is Elementary (EiE) curriculum introduces elementary school students to design through a storybook of a child encountering a design challenge followed by design experiences engaging in that design challenge. The K-12 Science Education Framework and Next Generation Science Standards emphasize integrating design into science and engineering instruction [13]. Additionally, the growth of the maker movement and academic maker spaces has increased access to informal project-based design learning experiences [7, 38].

Leveraging Design Experiences

While there are still calls for adding more design coursework to the engineering curriculum in higher education [10], it is difficult to find space. However, students are already engaging in many design experiences throughout their lifetime. In undergraduate engineering programs, students engage in formal design education experiences - such as cornerstone and capstone classes or design electives. Increasingly, students are participating in engineering coursework throughout their K-12 schooling. Students also engage

in professional design experiences through internships during their formal education and work experience following it.

We might also say that students engage in many informal design experiences throughout their lifetime. Herbert Simon famously states, “To design is to devise courses of action aimed at changing existing situations into preferred ones.” Given this definition, many of students’ informal everyday experiences have the potential to be seen as design.

An under-explored alternative avenue for improving design education is to focus on how we might help students get more out of the design experiences they are already experiencing.

Rather than engaging learners in more design experiences, how can we help them get more out of the design experiences they already have?

Supporting student’s design metacognition [1, 5] or “design awareness” [4] is a promising avenue for students to begin to make sense of their design experiences. The variation theory of learning [27, 29] offers a route for looking at how similarity and difference across design experiences can support learning.

Variation Theory

In addressing the open question of how we might support learners in getting more out of the design experiences they are already engaged in, numerous directions could be pursued. The variation theory of learning (VT) serves as inspiration, suggesting a design direction to follow.

Epistemological Foundations

Three strands of Research

Variation theory (VT) [27, 29] is a learning theory that is part of a trajectory of three strands of research - phenomenography [28], variation theory [27], and learning study [32, 33].

Phenomenography is a widely practiced research methodology aimed at cataloging the finite number of different ways people experience a given concept and the relationships between those ways of experiencing [3, 12, 28]. VT leverages some of phenomenography's epistemological assumptions but aims to explain how learning happens [3]. The final strand, learning study, seeks to bring about learning by leveraging phenomenography and VT for teacher professional development and the design of pedagogical interventions [3, 31, 32]. Learning study resembles action research and design-based research (DBR) [31] in that it has cycles of design and aims to advance practice while at the same time systematically surfacing empirical knowledge.

Foundational Concepts

While many epistemological foundations support VT, two key concepts are highlighted in consideration of Marton's quote below.

"We tacitly assume that what we see is exactly what is there to be seen and that others see things in the same way we do. It is hard to realize that we have actually learned to see the world in certain ways and that others may have learned to see it differently."[27]

Ways of Seeing: First, there are different ways an individual might experience ("see") the same concept [27]. For example, experts see problems in terms of features necessary for solving them, while novices see problems in terms of features that are easier to perceive but less relevant [27]. Take, for example, master chess players who "see" groupings of chess pieces rather than individual pieces [14, 22].

Perceptual Learning: Second, one learns to see things in a certain way. Variation theory is described as a "theory of differentiation," a kind of perceptual learning [15]. Perceptual learning is the idea that "human perception is, in large part, learned - that we learn to see depth, for instance, or form, or meaningful objects" [20] through practice and experience. Consider, for example, the wine connoisseur who can distinguish hundreds of different kinds of wine. Not everyone can distinguish in this way. It is learned by experiencing and differentiating characteristics of many kinds of wines.

Defining Learning

Given this foundation, we might ask how VT defines and conceptualizes learning.

Powerful Ways of Doing: In variation theory, the aim of learning is to be able to "handle relevant novel future situations in more powerful ways" [27]. For example, learning quadratic equations is not about being able to handle the equations you were taught in class but about being able to "deal with quadratic equations of kinds you have never seen"[27] in the future

Powerful Ways of Seeing: Learning, in this way, comes from being able to "see" a situation in more powerful ways. Marton describes two kinds of learning - 1) learning to see and 2) learning to do [27]. Learning to see (the focus of VT) occurs when the learners have discerned essential aspects of the object of learning and relations between them (for example, getting to a new location by learning geography). Learning to do is learning what to do to meet the demands imposed by the teacher or a test (for example, getting to a new location by memorizing the route). Learning to do is tied to the specific context and is not transferable.

Discernment: Akerlind [3] characterizes learning in VT as "an expansion in awareness." In VT, powerful ways of seeing are believed to come from the discernment of 'critical aspects' and 'critical features' [27] (described in the next section). Learning begins at the perceptual level with the learners' ability to make distinctions: tell something apart from the background of other things.

Key Concepts

Five key concepts related to the understanding and use of VT are described below.

Object of Learning

In any learning situation, there is a question of "what is to be learned" [27]. In variation theory, the 'what' is called the 'object of learning'[27]. For example, price and pricing [26, 31], chemical equilibrium [12], or "multiplication of multi-digit numbers" [27]. There are three different ways of "formulating" (describing) the object of learning: content, educational objectives, and critical

Example Study

The economic concept of pricing has been explored in a number of studies in the variation theory tradition (phenomenographies and learning studies). Studies worked with different age learners, from primary school to business school students, but the same object of learning.

A Defining Learning

we want learners to be able to handle novel situations of price in the future

B Ways of Seeing Price

(phenomenography)

more powerful ways of seeing

Outcome Space

- A **PRICE** depends on attributes of the **COMMODITY**
- B1 **PRICE** depends on peoples willingness to buy **SUPPLY**
- B2 **PRICE** depends on how much there is to buy by **DEMAND**
- C **PRICE** is a function of willingness to buy and how much there is to buy. **RELATIONSHIP** between supply and demand



C Object of Learning

Three Formulations

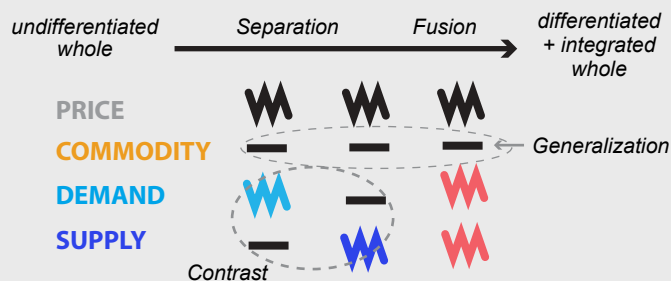
increasing specificity

- Content:** **PRICING**
- Educational Objective:** see the **PRICE** of a commodity in terms of the relationship between
- Critical Aspects:** discerning **SUPPLY**, **DEMAND**, and the **RELATIONSHIP** between the two



D Path of Learning (patterns)

We assume that students are level A in the outcome space - they have discerned price and commodity but not supply, demand, or the relationship between them. As such, the path of learning should be characterized by the patterns of difference seen below.



E Designing for Learning

(learning study)

A parallel learning study was conducted in five classrooms. An auction with four rounds was intended to create the patterns seen above.

F Measuring Learning

In carrying out the lesson plan, different things happened in each classroom leading to different patterns of variation.

- **Intended** object of learning
- **enacted** object of learning
- **lived** object of learning

Figure 2_1: This figure demonstrates core concepts of variation theory (VT) through an examples dealing with price and pricing.

aspects [32]. VT focuses on the third and most specific formulation - “critical aspects and features to be discerned” [27]. See Figure 2_1 item C.

Critical Aspects and Features

‘Aspects’ are dimensions of variation of the object of learning. For the ‘object of learning’ price in economics, supply and demand are aspects (see Figure 2_1 item C). ‘Features’ are values of the ‘aspect.’ For example, values of price might be \$1, \$5, or \$7.50. What makes an aspect a ‘critical aspect’ is that it must be discerned to understand

the ‘object of learning’ and that the learner has not yet discerned it [27]. Thus, what is critical depends on both the ‘object of learning’ and the learner’s previous encounters with the ‘object of learning’ [12, 27].

Path of Learning

In VT, learning is a trajectory from seeing the ‘object of learning’ as an undifferentiated whole to a deeper understanding of the object as a differentiated and integrated whole [27]. This is carried out by experiencing a sequence of

patterns of variation - first 'separation' (through 'contrast' and 'generalization') and then 'fusion.' In 'separation,' one 'aspect' varies while the others are kept constant. In the pattern of 'contrast,' 'defining aspects' of the 'object of learning' are discerned, while in the pattern of 'generalization,' non-defining 'aspects' of the object are discerned. In 'fusion,' many 'aspects' vary so that the 'aspects' and their relationships can be simultaneously discerned. An example of this trajectory for the economic concept of price can be seen in Figure 2_1 item D.

Designing Patterns (Learning Study)

The patterns described above are a trajectory of desired learner experiences. To make these patterns possible, examples must be compared and juxtaposed to allow for differentiation [27]. This is done in three ways: 1) grouping instances, 2) drawing attention to features in an instance, and 3) transforming instances [27]. While VT describes what patterns are needed and in what order they should be experienced, how to bring about these patterns is left up to the ingenuity of the educator or learning environment designer [27]. An example of a lesson implementing the patterns described in the previous section can be found in Figure 2_1 item E.

Measuring Learning

"Three faces" of the object of learning are articulated as a means of thinking about pedagogy and designing for learning - the 'intended,' 'enacted,' and 'lived objects' of learning [27]. The 'intended object of learning' is the 'critical aspects' that the learner **must** learn to discern for a given object of learning. The 'intended object' can be thought of as the planned goal of the learning engagement. In traditional pedagogical contexts, the educator typically determines the 'intended object of learning.' In more informal learning contexts, the 'intended object' may be determined by the learner or negotiated between the learner and others. The '**enacted** object of learning' is the 'critical aspects' that the learning situation makes possible for the learner to discern. Finally, the '**lived** object of learning' is the 'critical aspects' that the learner can discern at the end of the learning engagement. See Figure 2_1 item E for an example of how two implementations of the same lesson plan made possible different

'enacted objects of learning' and, as a result, yielded different 'lived objects of learning.'

Application

Variation theory has primarily been applied to understanding and supporting learning in two ways: first, as a lens through which to understand naturalistic learning activities that have already happened, and second, as a means of designing and assessing pedagogical interventions to better support learning. VT has primarily been used in K-12 education but has also been used in higher education.

Learning study [32, 33] is the most widely used pedagogical methodology for applying and assessing the use of variation theory in curricular contexts. Over 1,000 learning studies have been conducted in the last fifteen years [31]. It is a methodology akin to action research or design experiments [31, 33] based on the Japanese teacher professional development model "lesson study" [27]. In learning study, teachers collaborate to design, deploy, and assess lessons.

Phenomenography is used to surface 'critical features,' and VT is used to plan lessons with specific sequences of variation. Most lesson studies are conducted in series. Teachers will each implement the lesson in their classroom one at a time, observing each other and iterating for each implementation. Pre-tests and post-tests are administered to assess and compare how well students appropriated the object of learning as defined by their discernment of critical aspects.

Strengths + Weaknesses

The learning study application of VT consistently results in more substantial learning outcomes than control lessons [27]. However, several barriers exist to applying VT to design learning in engineering education.

Feasibility of Patterns: Variation theory states that people learn to discern through particular patterns of variance and invariance [27]. However, these patterns can often be challenging to deploy in learning scenarios [3]. VT does not offer guidance on implementing the necessary patterns of variation ('contrast,' 'generalization,' and 'fusion') in a learning environment. This

“next step” of embedding the patterns in activities students can engage in is “left entirely to the teacher or researcher’s own ingenuity” [27]. While many teachers intuitively recognize the need for variation in teaching, the role of invariance in helping students notice particular variation is much less intuitive. Teachers commonly vary multiple aspects of a concept simultaneously in an ad hoc rather than structured way, resulting in students not noticing the patterns of variation needed to discern ‘critical aspects’ [3].

Finding Critical Aspects: Another barrier to using VT is that it relies on knowing the ‘critical aspects’ of an ‘object of learning.’ These ‘critical aspects’ relate to both the learner and the object of learning and must be found [8, 26, 27]. As a result, before you can use VT to analyze or plan patterns of variation, you must “discover” the ‘critical aspects’ that need to be discerned. One way of finding ‘critical aspects’ for a particular ‘object of learning’ is through students’ learning difficulties. Places where students struggle suggest ‘critical features’ that students have not yet learned to discern [26]. In learning study methodology, critical features are identified through phenomenographic analysis of pre-tests, but can also be an outcome of the whole method [8, 33].

Research Question

As described earlier, more work is needed to understand how we might support students in getting more out of the design experiences they are already engaged in rather than squeezing more design experiences into a packed curriculum. Variation theory (VT) provides a fruitful lens to view our current design learning practices and suggest a direction for design research inquiry.

Consider, for example, some key concepts (objects of learning) in design, such as “divergent thinking,” “iteration,” and “design process.” Through the lens of VT, students can understand (see) these concepts in different ways. For a group of students, a hierarchy (outcome space) exists of different ways of understanding these concepts. To understand these concepts in more powerful ways, students must learn to see them in a certain way (perceptual learning) by discerning ‘critical aspects’ and ‘critical features.’

Discernment of ‘critical aspects’ of these concepts is enabled by experiencing specific patterns of variation in those aspects. If students engage in multiple design experiences or see the design experiences of others, they have an opportunity to experience differentiation. However, this is not a given. Furthermore, the tacit nature of design and distribution of projects across time might make it difficult to notice the variation even if it is there.

Students will likely benefit from learning environments that help arrange design experiences to be juxtaposed and make visible critical similarities and differences. However, the focus of current design teaching models is at the project level and course level. This focus helps students experience design and experience design more than once, but it does not necessarily help them discern critical aspects of design from seeing across instances of design. Consider a PBL course like a first-year experience or capstone design course. For one or two semesters, students engage in solving an authentic design problem on a team. Common course components such as critiques (peer review) or presentations increase the likelihood that students will experience variations. Still, there are limited systematic curricular efforts to design these experiences to make patterns of variance visible.

When considering the strict application of VT to design learning, there are many unknowns and some limitations. While there have been some studies of threshold concepts [25, 30] in design (e.g. [35]) education, there are no well-defined threshold concepts in design to help identify more narrow objects of learning to focus on. Additionally, there are limited phenomenography studies conducted on design as an object of learning [2, 16], and critical aspects and features have yet to be identified at a granularity that supports applying the learning study method to create curriculum and assess learning.

While there is limited focus in our current learning environments on learning from seeing across instances of design, the emphasis on project-based learning has generated a proliferation of student design experiences that we might leverage. In this proposal, the following design research question is asked:

How might we design environments that support learning from seeing across individual design experiences?

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Chapter 3: Research Through Design

Since the methodologies used in this work are novel in engineering education research, this chapter provides a methodological background and justification for their relevance. The methodologies - research through design (RtD) and annotated portfolios (AP) - are first outlined. Then, the fit of these methods for engineering education is discussed.

Research Through Design (RtD)

Design as a Research Method

Research through design (RtD) is a research methodology that borrows its methods from design and its goals from research [56]. In many ways, the methods and goals of design and research are quite disparate and in tension. Figure 3_1 outlines some of these tensions. Broadly speaking, research seeks to generate new knowledge, while design seeks to create artifacts that do not yet exist [51]. Another tension is that design focuses on the future while research focuses on the past or present [56]. Many research methodologies exist for surfacing knowledge, but these processes are significantly different from the design process. There are, however, areas of “design research” where these disciplines overlap. Frayling offers a framework for characterizing three kinds of design research based on their methods and knowledge contributions [13]. These three kinds of design research are research “into” design, research “for” design, and research “through” design (RTD). See Figure 3_2.

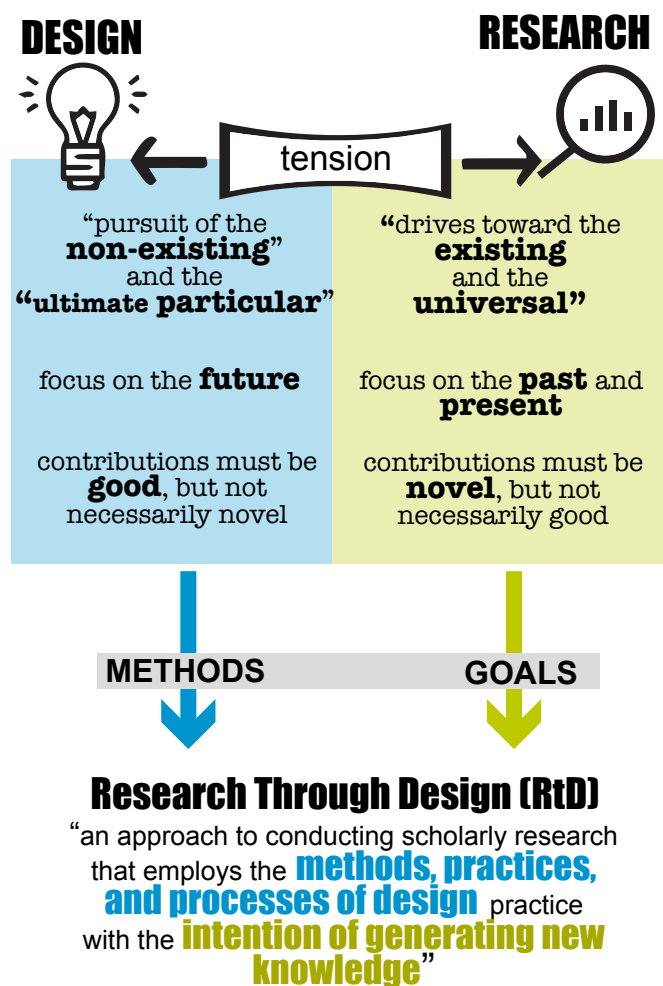


Figure 3_1: This figure illustrates the tension between design and research and how RtD leverages methods from design and goals from research. Stolterman characterizes design as the “pursuit of the non-existing” and “ultimate particular while science drives toward the “existing” and “universal” [51]. Zimmerman and colleagues describe a tension between designs focus on the future and research’s focus on the past [56]. Finally, Zimmerman and colleagues note that design aims to be “good” while research aims to be novel.

Research “into” and “for” design are characterized by the type of knowledge created by the research process [56]. Research “into” design produces knowledge about the practice of design. Consider, for example, Donald Schon’s ethnographic research on architecture that led to the concept of “reflection-in-action” [48] or Herb Simon’s work using verbal protocol analysis to understand design process and cognition [50]. Research “for” design is “research intended to advance the practice of design” [56]. Research “for” design includes research that has implications for design or new design methods—for example, the wealth of research on ideation techniques.

In contrast, research “through” design (RtD) is characterized by the methodology used to conduct research. In the examples above, ethnographic or experimental methods were used to surface understanding of design or to help the doing of design. RtD combines design methodologies (problem scoping, ideation, prototyping) with research goals (producing knowledge). Zimmerman and Forlizzi define RtD as

“an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge” [56].

History and Use

Research through design (RtD) comes from the interdisciplinary field of human-computer interaction (HCI). It was introduced in the early 2000s and developed from a need to leverage the knowledge generated by interaction designers [16, 21, 55]. Dunne and Gaver [16] proposed a new “design-centered” approach to HCI research as part of an “ongoing attempt to understand how we can do research while respecting the methods and perspectives of designers” [21]. They suggest a new role for designers in “raising deep questions about the meaning of digital media and in suggesting alternatives to our current assumptions” [16].

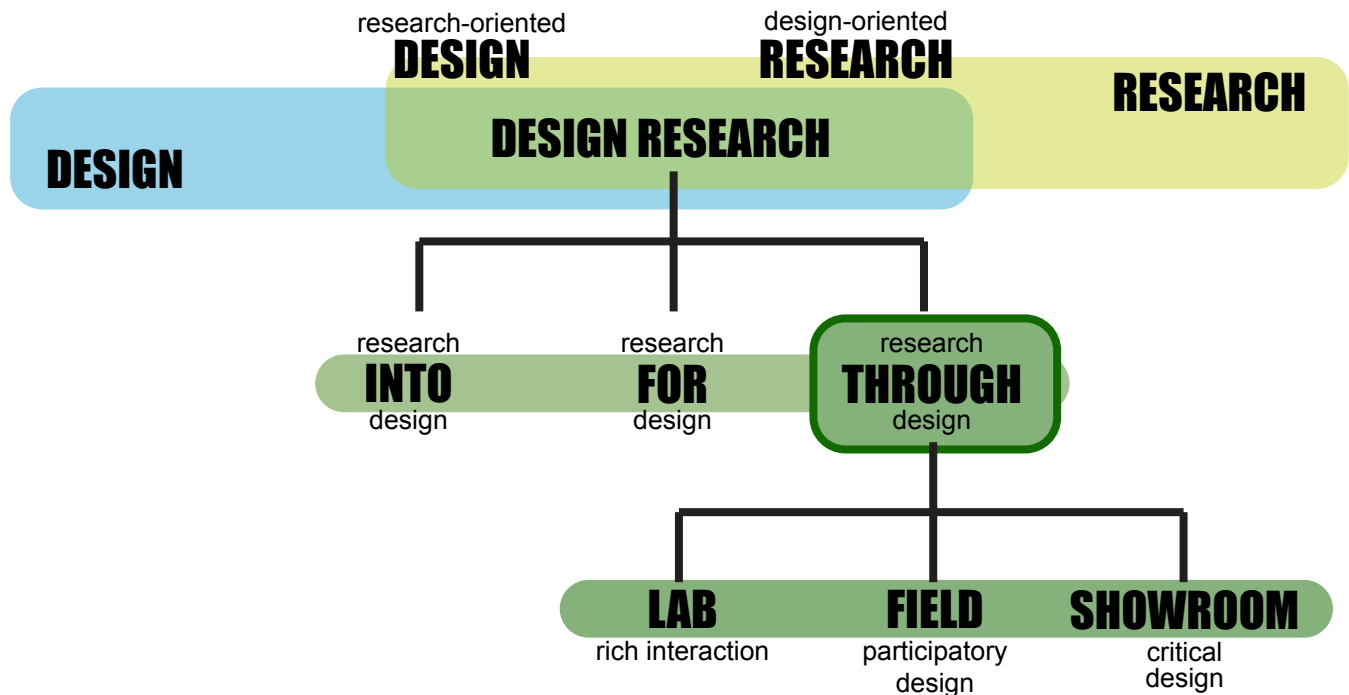


Figure 3_2: This figure depicts the kinds of research characterized by the overlap between design and research. The top row articulates Fallman’s categorization of research-oriented design and design-oriented research [17]. The middle row presents Frayling’s three kinds of design research [13]. Finally, the bottom row shows Zimmerman and Forlizzi’s [56] characterization of three kinds of research through design.

RtD is seen as a response to the challenge in HCI that “things proceed theory” [56]. A classic example of this in HCI is that the computer mouse needed to be invented before it could be shown to be a good design. RtD has achieved increasing interest and attention in HCI. RtD has recently cross-pollinated to the food design research community [54]. However, RtD has been used very little in engineering education research.

RtD is described as a methodology rather than a method because it describes a system of practices aligned with the belief that creating design artifacts uncovers new knowledge [41]. Zimmerman and Forlizzi suggest several categories of RtD - lab, field, or showroom [56]. Practitioners of RtD describe a variety of methods that extend or fall under the broad umbrella of RtD, such as design fictions [34], critical design [56], speculative design [32], research products [41, 43], material speculation [24, 41], embodied design ideation [32], critical making [32], participatory RtD [54], collaborative futuring [28], and research through explorative design [26].

Knowledge Production

Development and use of theory is the core of research and knowledge production. In older positivist and interpretivist traditions, standards for theory development and use are well articulated. However, in RtD, there is still much debate, partly due to the fundamental tension between design and research [56]. Stolterman characterizes scientific research as focused on the “existing” and “universal,” while design is in pursuit of the “non-existing” and the “ultimate particular [51].”

There are calls for consolidation of practice and definition of rigor in RtD [21]. While some authors turn towards positivist or interpretivist metrics for rigor, Gaver points out that there is a mismatch between design knowledge and how we view scientific knowledge. Design practice is generative and underspecified by theory. As a result, we should expect design theory to be provisional, contingent, and aspirational instead of extensible and verifiable [21]. RtD produces knowledge referred to as “intermediate level knowledge” [33], a “type of design knowledge that lies between [generalized] theories and design instances” [24]. Gaver [20, 21] proposed a method of treating

annotations as theory called annotated portfolios (described in detail in the next section). In these portfolios, the design issues, decisions, and rationale are used to annotate visual artifacts of design. Once synthesized, these collections of designs surface design theory.

“We should expect design theory to be provisional, contingent, and aspirational instead of extensible and verifiable.” [21]

Trustworthiness in RtD

There is a need in all research to establish “trustworthiness” and account for quality [49]. In positivist quantitative research, measures of reliability, internal and external validity, and objectivity are used to ensure trustworthiness [15]. These measures fundamentally do not apply to interpretivist research where “knowledge is concerned not with generalization, prediction, and control but with interpretation, meaning and illumination” [52].

As a result, new metrics or adaptations of these metrics have been proposed. For example, qualitative researchers have widely used Guba’s [23] metrics of credibility, transferability, dependability, and confirmability [49]. Building on this framework, Shenton provides strategies to consider and ensure trustworthiness in qualitative work [49]. Walther instead adapts the metrics for Engineering Education, suggesting that quality should be continuously assessed throughout the work based on validation (accuracy) and process reliability (precision) [53].

Nelson and Stolterman [35] position design as a “third way, “ separate from art and science, so how these communities’ metrics might apply is unclear. There is a call in RtD for “actionable metrics for bringing rigor in critique of design research” [18], but there is debate as to what those should look like. The work of designers has been positioned as subjective [16] and is seen as closer to the interpretivist research paradigm [57] so interpretivist metrics may apply. Some specific metrics have been developed. For example, Zimmerman and colleagues [57] propose a set of

General Methodology

1. Select

A: Problem or Opportunity

Select a design research problem or opportunity to investigate.

designing for utilitarian interactions
multi-species *ludic* *slow*

B: Narrow

Narrow focus based on a domain and theoretical principles.

theory *collaborative survival* *promote curiosity + reflection* *unawareness, intersections, + ensembles*

domain *mushroom foraging* *surfaces in the home* *digital music players*

2. Design

A: Prototype

Create a design prototype.

hand-substrate interface *drift table* *Olly music player*

B: Document

Create traces of design product, process, and rationale that can be used to later reflect on and surface knowledge.

3. Evaluate (Analyze)

A: Reflect

Surface knowledge through reflections on the design decisions and rationale.

B: Deploy

Conduct autobiographical testing or field deployments of artifact.

4. Disseminate

Share findings through articles, presentations, exhibits, etc.

5. Repeat

Create multiple RtD artifacts based on the same design research problem.

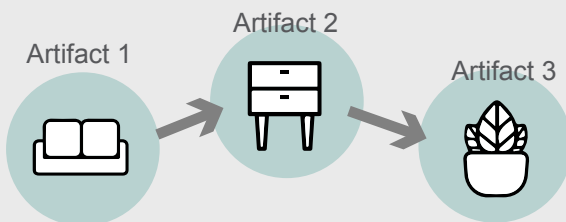


Figure 3_3: This figure depicts the 5 major steps of the RtD process.

criteria - 1) Process, 2) Invention, 3) Relevance, and 4) Extensibility - for evaluating the quality of an interaction design research contribution.

Gaver, in contrast, does not see science as an appropriate model for design and argues that due to the generative nature of design, we should not expect design knowledge to be generalizable and falsifiable - “the goal of conceptual work in research through design is not to develop theories that are never wrong, it is to create theories that are sometimes right.” [21]. He suggests the role of theory as annotation through annotated portfolios [21].

Methodology

In HCI, RtD inquiries are conducted by multidisciplinary research teams that typically include interaction designers, ethnographers, and computer scientists [22]. The full scope of an RtD project, including multiple iterations of design and deployment, is often several years [35]. Zimmerman and Forlizzi suggest five steps for carrying out RtD: 1) Select, 2) Design, 3) Evaluate, 4) Reflect and Disseminate, and 5) Repeat [56]. A modified list of these steps, based on descriptions of practice in the field, can be seen in Figure 3_3.

The first step in an RtD project is identifying a design research problem or opportunity to pursue. In the HCI literature, many inquiries frame their aims or motivation as “Designing for <blank> interactions.” The blank is filled in with innovative new ways of looking beyond utilitarian design. For example, Gaver and colleagues have explored designing for “ludic engagements” [22]. Ludic engagements are “activities motivated by curiosity, exploration, and reflection rather than externally defined tasks” [22]. Other areas of design include designing for slow [41, 42] interactions, collaborative survival [32], touch[8], acoustic sonifications [1], human food interactions [2, 3], collaborative interaction [44], and personal and interpersonal connections [9].

As these design research problems are broad, the next step is to narrow the research focus. Narrowing focus may be done by selecting a new technology or material, target population, context, or theoretical framing to apply [56]. For example,

when creating the “drift table,” Gaver and his team hypothesized that promoting curiosity and reflection and de-emphasizing external goals could help promote ludic interactions [22]. These become the guiding principles for their design. They were interested in using surfaces in the home, so they chose a table as a kind of object to experiment with. In Lui’s investigation of multi-species interaction, interactive wearable tools were selected to explore human-fungi relationships [32]. Inspired by the theoretical concepts of unawareness, intersections, and ensembles and last.FM technology, Odom investigated the broad concept of designing for temporality through the Olly digital music player [41, 42].

The next step in an RtD inquiry is to design. Teams of designers and researchers create a new artifact or system to generate knowledge. In the context of HCI, these artifacts take the form of furniture [22, 25], jewelry [9], music players [38, 41, 42], or wearables [4, 32]. For example, Dunne and Gaver created a pillow that lights up based on electromagnetic radiation in the area [16]. To explore “slow” interactions, Odom and colleagues created Olly, a music player that allows users to re-experience music they listened to in the past [41, 42]. During the design phase, documentation of the design process, decisions, and rationale is collected. Documentation often takes the form of photos of the artifact and notes taken throughout the design process.

The next step in the RtD process is the evaluation, or analysis, of the designed artifact. Knowledge is drawn from reflecting on design decisions and rationale. The creation of and reflection on the artifact is often accompanied by additional data collection and analysis methods. Autobiographical design techniques (e.g. [32, 36]) involve the designers testing out the designs on themselves. Many authors conduct “field deployments” [8, 32, 42] following the design phase. One deployment can last anywhere from a few weeks [25] to over a year [42]. For example, Olly – the slow technology music player - was deployed with three users for 15 months in the home [42]. During these deployments, techniques such as interviews, photos, and user reflections are used to surface knowledge about the user’s interaction with and experience of the designed artifact.

Workshops are another method used to collect user interaction data.

In the dissemination phase, sharing the designed artifact is a source of RtD knowledge. A description of the designed artifact and rationale for design decisions is a key aspect of what is communicated back to the research community. Many authors describe their contributions as moving theory into practice [32, 41]. Knowledge contributions often also include tactics for designing for these new kinds of interaction [32].

The final step in the RtD process is to repeat the previous steps. Koskinen notes that more substantial research results come from RtD research programs that repeatedly investigate the same design research problem than from individual RtD research projects [29]. An example of such a research program is the Goldsmiths Interaction Research Studio at the University of London. This studio has developed a series of RtD artifacts (e.g., the drift table [22], photo stroller, and prayer companion [19]) to investigate “ludic” interaction. Researchers outside this studio have even begun contributing to this RtD topic by extending ludic design to specific domains, such as human-robot interaction [31]. The investigation of ‘slow’ interaction and temporality at Simon Frasier’s Everyday Design Studio is another example of such an RtD research program. Several design artifacts, including the Olly music player [41, 42], slow game [37, 41], photo box [38–40], Olo Radio [38], chronoscope [11, 12], and table-non-table [25], have contributed to a more robust understanding of how to design for temporality.

Annotated Portfolios

Annotated portfolios [19, 21, 33] are one of a growing list of techniques for theory articulation in RtD. They were introduced into the HCI community in 2011 [21] as a methodology for eliciting theory through annotations of a collection of related RtD artifacts.

The Logic of Annotated Portfolios

Research aims to produce knowledge (theory) that can inform future research and practice. The role of theory in RtD is highly discussed due to

the tension between the “generality” of scientific theory and the situated, multidimensional, and embodied nature of design. Gaver and Bowers argue that theory by necessity under-specifies design [19, 21]. Design often addresses wicked [45] and complex problems for which there is no correct solution a priori. Practitioners are faced with innumerable decisions, whatever theory they use, and a given theory will not capture many aspects of a successful design. As a result, design theory should be expected to be provisional, contingent, and aspirational rather than “extensible and verifiable” [21]. Annotated portfolios are proposed as a means of “communicating design thinking in HCI in a descriptive yet generative and inspirational fashion, without having recourse to standards of ‘theory’ which fit design poorly” [6].

Gaver and Bowers describe theory as playing an “unexpected,” “indirect,” and “humble” role in design practice [19]. They argue that specific concrete design examples are more important in informing design practice than theory. Gaver refers to the artifacts as the “definite facts” of research through design [21]. Stolterman argues that the “ultimate particular” in design has the “same dignity and importance as truth in science” [51]. Carroll and Kellogg [10] refer to designed artifacts as a “theory nexus,” arguing that designer’s choices reveal the issues they think are important and their beliefs about the right way to address those issues.

A myriad of multifaceted choices, concerns, and rationale go into designed artifacts. These are the “facts” of design. However, these issues are not explicit in the final artifact and must be drawn out by the designer through annotations [19]. Gaver states that “instead of theories predominating, with design examples serving as mere illustrations, design theory is best considered a form of annotation, serving to explain and point to features of ‘ultimate particulars,’ the truths of design [21].”

Annotated portfolios combine a collection of specific design examples and surface the issues, decisions, and rationale embedded in these designs through annotations. Annotated portfolios honor the particularity of specific design examples while still drawing out broad and applicable concerns. This synthesis is described as capturing “family resemblances” amongst the

collection of artifacts [19], articulating dimensions in design space [21], or drawing out “conceptual themes” [24] that may be generalizable to other designs.

The annotated portfolio method is not highly prescriptive but “open to interpretation and appropriation” [19] based on the material, purpose, audience, and research goals. Gaver and Bowers describe offering a “methodology for communicating design research, but not a restricted toolkit of methods” [19].

Though there is flexibility in carrying out the annotated portfolio method, the integrity of the method comes from a balance between detailed examples of design practice and annotations articulating the issues, values, and themes that characterize the relations in the collection. Gaver describes this as a “mutually informative juxtaposition of conceptual annotation with specific design examples, in such a way that neither dominates, and neither is subservient” [21].

Gaver and Bowers [6, 19] articulate seven core features of annotated portfolios: constitution, relationship, communication, perspective, mutual informing, shaping, and materiality. These features are not ordered (in terms of implementation or importance) but “jointly working to give an extended sense which should show how the notion of an annotated portfolio can be put to use in RtD and HCI” [19].

- **Constitution:** Annotations make a collection of designed artifacts into a portfolio. They bring together individual artifacts as a systematic body of work.
- **Relationships:** Annotations capture family resemblances between designs in a mesh of similarities and differences.
- **Communication:** Annotations communicate the nature of the portfolio and enable its comparison with others.
- **Perspective:** Typically, a portfolio can be annotated in several ways, reflecting different purposes, interests, and audiences.
- **Mutual Informing:** Annotations and the designs they annotate are mutually informing.
- **Shaping:** Annotations can shape how artifacts are used, how they might be appreciated and understood, and suggest

future research and design possibilities.

- **Materiality:** Any material form can be considered for an annotated portfolio, including an illustrated monograph, a scientific paper, or a curated exhibition.

Methodology

While carrying out an annotated portfolio is somewhat open-ended, the process entails four steps:

- 1) **Identify + Select:** Specific examples of RtD design artifacts are identified and collected
- 2) **Represent:** Details of these designs are represented in an appropriate medium.
- 3) **Annotate:** Designs are annotated with articulations of issues, values, and themes characterizing the relations among the collection and to which the examples suggest answers.
- 4) **Synthesize:** Themes are inductively generated from the annotations.

Identify and Select

When generating an annotated portfolio, choices must be made about what design artifacts to include in the collection. Selection includes consideration of the total number of artifacts and the source, fidelity, and kind of artifacts to include. The method is not highly prescriptive, but choices should reflect the interests of the intended audience and research aims [6]. The rationale for such decisions is seldom articulated in research papers, but benchmarks can be drawn from looking at current practice through published portfolios. Annotated portfolios include as few as two and as many as over twenty artifacts (e.g., [3, 14, 27]). For portfolios of previously published RtD projects, the portfolio size is usually four to nine design artifacts (e.g., [1, 6, 24, 26]). Collections of higher numbers include non-RtD designs from art and industry or iterations of one RtD design artifact (e.g., [3, 14, 47]).

Annotated portfolios were initially conceived as a collection of completed RtD artifacts, each field tested and fully documented in separate publications (e.g. [6, 24, 26]). The collection of designs that have been prototyped and tested is what sets an annotated portfolio apart from design workbooks [20, 21]. Hauser emphasizes

the importance of selecting artifacts that have been field-tested, not just conceptualized [24]. Involvement in projects also helps create a more robust portfolio. First-person accounts provide rich annotations and holistic understanding through deep knowledge of the design rationale and evaluation [44, 47].

However, some research has diverged from using first-person accounts and published RtD artifacts in the portfolio. For example, Schilling, Wakkary, and Odom selected prototypes of one RtD project for their portfolio[47]. In a few portfolios, authors selected designs from research, industry, and art [14, 46] or common practices [3] that were not first-person accounts or artifacts from RtD studies. In these cases, the rationale, issues, and values embedded in the designs are much more challenging to surface through annotations.

Many portfolios include design artifacts from a specific designer or research lab (e.g. [1, 6, 26, 44]). Bowers notes that “a collection might be from a single designer, project, or studio,” however, this is not required [6]. Some portfolios instead include collections generated from classes and workshops [3, 9] or selected from a large body of published works or well-known designs [14, 46].

Very few articles describe the selection criteria for portfolio items. For many portfolios, the choice seems to be based on a predefined collection. Hauser is an exception[24]. In this annotated portfolio, researchers describe selection criteria based on their chosen perspective - interest in seeing RtD as doing postphenomenology. They collected 30 artifacts from searching published articles, images, and videos. Next, they curated items based on their methodological commitments (perspective), the presence of field deployments, and the breadth of source materials (i.e., from different research studios and design researchers).

Represent

In addition to identifying the artifacts to include in the portfolio, the representational form of the portfolio must be decided. The appropriate form depends on the audience, RtD artifacts, and research goals. Choices for the form include video, stage show, images, and collections of postcards. However, most of the published

portfolios in the HCI community follow Gaver's [19] example of photos with a few annotations (e.g. [3, 27, 44]). Many portfolios use a digital medium, though Schilling and colleagues chose the medium of post-it notes on a wall for their portfolio [47]. In a portfolio, each RtD artifact is typically represented by one to five photos depicting key design features. Hall extends the AP method to include process and artifact [23]. As a result, this portfolio includes pictures of each artifact at different points in time.

Annotate

One of the seven features of annotated portfolios is "perspective" - what is highlighted by choosing what to include in the portfolio and what to annotate. A portfolio can be annotated in several ways [6]. Bowers, for example, describes the decision to focus on "interaction qualities" rather than "ludic design" or "threshold devices" as he feels these works have contributions to interaction design which has not been fully articulated yet [6].

The annotated portfolio's perspective is often the same as the RtD inquiry. For example, acoustic sonification [1], personal and interpersonal connectedness [9], collective interaction [44], or intimate interpersonal touch [26]. In these cases, the design research question for individual artifacts and the annotated portfolio's perspective are the same. In some studies, a different perspective was chosen for the portfolio. For example, Hauser is interested in the alignment between speculative RtD and postphenomenological commitments. Their portfolio annotated a diverse collection of RtD artifacts with the perspective of "postphenomenology commitments" [24].

Perspective is used to annotate features of the designs included in the portfolio. Annotations are often depicted as short descriptions placed around the photos and oriented using arrows and lines. Sauerwein, for example, shows an extensive collection of color-coded annotations grouped around one image representing each design [46]. Hall shows annotations organized to the side of a collection of photos depicting each design [23].

Many published annotated portfolio studies do not show detailed annotations (e.g. [19]), while others do not provide visuals of their portfolio

at all (e.g. [1, 6, 24]). This makes it challenging to assess portfolio representation practices, as what appears in publications is often a high-level diagram for explanatory purposes rather than the detailed portfolio used for eliciting information.

Synthesize

Once the RtD design artifacts in the collection are annotated to identify design issues, decisions, and rationale, these annotations are synthesized. Themes are inductively surfaced using properties such as space and color to sort and group the annotations. This results in categories of annotation that can be seen across the artifacts.

Published APs in HCI result in two to eight themes, though three or four are more common (e.g. [1, 3, 9, 24, 27, 44, 46]). Not necessarily every theme is seen in every project [6]. For example, Hoby's portfolio presents a progression of RtD artifacts in which new characteristics come from new projects [26].

The results of the portfolios are "conceptual themes" that represent key "attributes," "values," or "qualities" of the design research problem and perspective chosen. For example, Bertran is interested in designing for human-food interaction. Their portfolio of 27 playful food traditions results in four "play food potentials": playing with inedibles, playing with the materiality of food, playing with the physical space, and playing with rhythm and social norms [3]. Hoby and colleagues are designing for intimate interpersonal touch. Their portfolio of five RtD artifacts results in four qualities (or interaction aesthetics) of touch: novel connotations, sparking curiosity, social ambiguity, and norm-bending intimacy [26].

Beyond the AP

In a few cases, the portfolio results are taken further to create frameworks for supporting design (e.g., [14, 44, 47]). Schilling and colleagues' analysis of 15 prototypes of one RtD project resulted in the "Focus Framework" [47]. The framework supports post hoc analysis of the design process to understand how intended and unintended design attributes affect the final design product. While the framework emerged from the themes uncovered by the AP, it is distinct from it. The authors describe the framework

as a “discrete analytical tool which emerged through the combination of higher level categories created while iterating the annotated portfolio and attaching elements of it to a timeline” [47].

Through an annotated portfolio of over 40 “social wearables” from industry, art, and research, Dagan and colleagues surface support potentials of social wearables [14]. Their framework for social wearables was developed by focusing on how and why these wearables support certain potentials. The framework was then tested on two projects.

In an annotated portfolio of seven collective interaction “research prototypes,” Peterson surfaced five qualities of collective interaction [44]. These qualities were combined and substantiated by theory in the field to explore three themes through “annotated mappings” and “re-design sketches.” The annotated mappings plot the seven projects along each theme, while the re-design sketches suggest future directions.

RtD in Engineering Education

To understand how engineering education research (EER) might benefit from RtD methodology, we first need to understand the state of research methodology in engineering education.

Engineering education is a relatively young and developing field. Many practicing researchers were trained in fields, such as engineering, that teach quantitative positivist research methodologies [5]. The rise of engineering education research programs (such as the School of Engineering Education at Purdue) has led to training in different methods and broadening the use of research methods in the field. Much engineering education research is currently quantitative, likely because most engineering educators have quantitative training [5]. Borrego argues that engineering education is undergoing a paradigm shift [30] to more mixed methods. There has been a push in the community to train and use more qualitative and mixed methods approaches.

Present	
Questions	Methods
What reflection activities do instructors use in the engineering classroom?	survey
Do students with higher spatial reasoning skills have higher design reasoning skills?	experiment
What are the different ways students experience the concept design thinking?	phenomenography
What differences are there between novice’s and expert’s design practices?	verbal protocol analysis
How is the design process conceptualized in engineering education text books	content analysis
How do engineers deploy ideation strategies in the wild?	video ethnography
What are the experiences and perceived barriers of minority students first-year design programs?	interview
Future	
Questions	Methods
How might we design for more inclusive learning environments?	design research
How might we design for multicultural engineering education?	design research
How might we design practices that support students in synthesizing the design experiences they have throughout their education?	design research

Figure 3_4: This figure shows a series of engineering education research questions and associated methods. On the top are a number of traditional research questions about the present. On the bottom are research questions that are about the future and therefore require design research methodologies.

Many authors argue that there is no universally preferred research method but that the method should be matched to the research question. Borrego encourages cross-pollination of methods across disciplines and argues that open dialog of alternative methods would benefit the field by allowing researchers to more appropriately choose methods to address different research questions [5]. Ann Brown, known for developing design-based research (DBR) in the learning sciences community, made the case that the community's questions had changed, so the methods also needed to change [7].

While the recent adoption of new methods has allowed engineering education to ask and answer different kinds of research questions, there is a gap in the ability to ask future-oriented questions. As mentioned earlier in this chapter, RtD can be seen as a response to the challenge in HCI that “things proceed theory” [56] – the idea that something first needs to be designed before it can be shown to be good design. We have a similar challenge in engineering education research - innovative learning environments need to be designed before we can prove them to be good learning environments.

Quantitative and qualitative methods answer questions of “what is.” We do not currently have methods for answering questions of “what might be.” Figure 3_4 provides a list of different research questions and associated methods. For example, a survey methodology would be appropriate for a research question about current practices of reflection in engineering courses. Interviews and thematic analysis would be appropriate for a research question about the lived experiences of minority students in engineering education. These examples ask and answer questions of the present – “what is.” Consider the question posed in this proposal: How might we design learning environments to support learning by seeing across design experiences? To answer questions of what could be, we need design research methods.

RtD was developed in the field of Human-Computer Interaction. This field has different expertise, research questions, and assumptions about the world than engineering education. As such, there may be elements of the methodology that need to be creatively adapted to an

engineering education context.

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Chapter 4: Approach

A three-stage approach was used to address the design research problem and opportunity of “How might we design environments that support learning from seeing across individual design experiences?” As this work aims to explore questions of “what could be” rather than “what is,” a design research methodology was used. RtD inquiries were conducted to investigate the design research question, the annotated portfolio method [4, 5, 12] was then used to analyze many RtD artifacts, and finally, a framework was developed by aligning the results of the portfolios to the variation theory of learning [13, 14]

Two Sites of RtD Inquiry

The basis for this analysis was a series of RtD inquiries I conducted over four years between 2017 - 2021. These inquiries all addressed the broad design research problem (and opportunity) of designing for learning through seeing across individual instances of design work. Inquiries were conducted in two different sites of learning. As the design research question is learning-oriented, the resulting RtD artifacts considered here are learning environments. Both sites were courses taught in a human-centered design department within a school of engineering at a large public university.

The first site, ‘Making and Mapping,’ was a research seminar dedicated to helping students learn design by researching their own design processes. Three iterations of this seminar were carried out during the Fall of 2017, the

Spring of 2018, and the Winter and Spring of 2019. The second site, Explorations in Human-Centered Design, was an introductory design course in which some activities were designed to address the design research questions above. Two iterations of this course were carried out in the Fall of 2020 and Winter of 2021. A visual representation of the two sites of learning and three iterations can be found in Figure 4_1. Each course contained several learning activities to answer the same design research question. Both courses included project-based learning.

The Making and Mapping Seminar

The first site, ‘Making and Mapping’ (M&M), was designed and taught as a two-credit nongraded research seminar offered to undergraduate and master’s students within and outside the department. The seminar was an informal project-based learning community comprised of small groups of seven to twenty-one students. This seminar aimed to support students’ design learning by engaging them as co-researchers of their own design practices and process.

The seminars were carried out in one to two ten-week quarters. Students engaged in personal fabrication projects in the university’s maker spaces, documented and reflected on their design work, and then compared and analyzed their collective work together in one to two weekly group meetings. The department had a precedent of offering several research seminars led by faculty and graduate students. Within that structure, I designed and taught all three

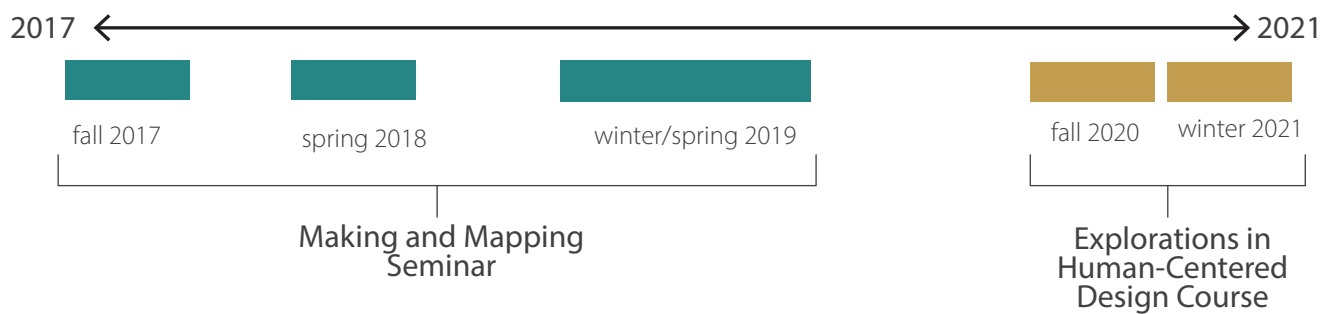


Figure 4_1: The research through design (RtD) inquiries took place in two sites of learning. The first site, 'Making and Mapping,' was a research seminar. Three iterations of this seminar (depicted in blue on the left side of the diagram) were carried out during the Fall of 2017, the Spring of 2018, and the Winter and Spring of 2019. The second site, Explorations in Human-Centered Design, was an introductory design. Two iterations of this course (depicted in yellow on the right side of the diagram) were carried out in the Fall of 2020 and Winter of 2021.

seminars.

Scope of RtD

In the M&M seminar, the scale of RtD inquiry was at the course curriculum level. The whole seminar was designed as a response to the design research question. In this case, the general design was to engage students as co-researchers of their own process to learn by seeing across individual design experiences. The seminar was designed to support students in engaging in informal making, documenting their experiences, and collaboratively comparing their design experiences. Within the scope of the ten-week seminar, activities within those units were also designed to support the design research goal.

Iterations

There were three iterations of the Making and Mapping seminar. This first iteration of the seminar (M&M_1) was conducted in the Winter quarter of 2017 and lasted ten weeks. Seven undergraduate students participated. The informal project-based design learning topic was left open-ended, and students were asked only to “learn to use the maker space” and document their process through field notes and reflection entries. One two-and-a-half-hour meeting was held each week where students shared a project update and engaged in a discussion based on topics of interest.

The second iteration of the seminar (M&M_2) was conducted in the Fall quarter of 2017 and lasted ten weeks. Seven undergraduate students participated. The informal project-based design learning was focused on the domain of sewing. Learners were asked to pursue a project

primarily using sewing resources in a particular maker space on campus. Learners were asked to document their process through field notes, reflection entries, discussions, and qualitative analysis in group meetings. In this iteration, we began to look at the time element of students’ design process using Post-it notes and a large sheet of paper to make a timeline each week.

The third iteration of the seminar (M&M3_a and M&M3_b) was conducted in the Winter and Spring of 2019 and lasted twenty weeks. Twenty-one students participated in the first quarter, with twelve continuing to the second quarter. The informal project-based design learning was further focused on one fabrication technique. Students were asked to pursue a project that primarily used laser cutting, was based on a tutorial, and involved three iterations over the ten-week quarter. Students were asked to document their experiences through design journals, log entries, reflections, process diagrams, and discussions. Two meetings were held weekly, one in small groups to support the informal design work and one including all students to support collaborative research about their collective design process and experiences.

The Explorations in Human-Centered Design Course

The second site, Explorations in Human-Centered Design (EHCD), was a three-credit graded introductory design course taught in the same department and university as the M&M Seminar. Enrollment in the course was around seventy-five undergraduate students. This course used a

project-based learning pedagogy to help students explore human-centered design principles and methodologies. The course comprised ten units that explored interaction design, usability testing, ideation, user research, physical computing, information visualization, and ethical practice. During the ten-week quarter, students engaged in eight design assignments. This included an introduction to a user-centered design workshop, six one-week design sprints, and three iterations of a responsible design practice essay.

The course was taught in a flipped-classroom-like format. Students were exposed to content through “studio prep” assignments with preparatory readings and videos. Concepts were then reviewed and practiced in the two-hour studio section. Students started their design project assignment in the studio meeting and completed it as homework. The weekly fifty-minute “lecture” meeting included students from all three studio sections and was often used for guest lectures in prior course iterations. Finally, after completing their design assignment, students engaged in peer critique or reflections on their work.

EHCD was designed for an in-person studio setting by two faculty members. It was taught nine times by different instructors in an in-person format using the department’s design studio space. In the spring quarter of 2020, due to the COVID-19 pandemic, this course was shifted to a remote format. I had an opportunity to teach this course remotely during the Fall quarter of 2020 and the Winter quarter of 2021. While not involved in the initial design of the course, I made some modifications to learning activities during these two quarters to better adapt the course to a remote learning format.

Scope of RtD

While the whole learning environment of the Making and Mapping seminar can be seen as a response to the design research problem, in contrast, only a few activities with the EHCD course were designed as RtD inquiries.

Teaching does not always involve design or redesign. In the case of EHCD, this course was already designed and had been significantly tested and refined over several years. However, due to the COVID-19 pandemic, design problems

emerged from the shift of the course to a remote learning format. In response, I adapted the “lecture” meeting and peer critique assignments into weekly activities that engaged students in learning through seeing across design examples. Further details are described in Chapter 5.

Iterations

Two iterations of the Explorations in Human-Centered Design course included RtD inquiry. The course’s first iteration of RtD inquiry was carried out in the fall quarter of 2020 (EHCD_1). This was my first involvement in the course. The RtD inquiry here was a series of activities called Design in the Wild.

The course’s second iteration of RtD inquiry was carried out in the winter quarter of 2021 (EHCD_2). During this quarter RtD inquiry activities were more strategically designed as an iteration of the activities of the prior quarter. Students engaged in ‘seeing across projects’ activities each week during the fifty-minute lecture.

Annotated Portfolio Analysis

The annotated portfolio (AP) analysis of RtD inquiries was carried out iteratively. The first analysis focused on breadth and looked at over fifty “RtD artifacts.” This analysis was followed up by a second depth-focused annotated portfolio analysis of seven “RtD artifacts” from the two sites of learning described. The AP process outlined in Chapter 3 is followed here: 1) identify and select, 2) represent, 3) annotate, and 4) synthesize.

Defining the Unit of Analysis

An annotated portfolio analyzes several “RtD prototypes” created as unique answers to the same design research question. As practiced in HCI, the designed artifacts that make up the portfolio are often physical objects (tables [6, 8], music players [16, 17], wearables [1, 11]). In using this method for engineering education, consideration was needed for what would be considered the “RtD prototype.” Both scale and aspects beyond physical “artifacts” were considered.

The scale must be considered when considering the “design artifact” in engineering education. Lemke writes about different timescales in education [10]. He articulates a range of processes from chemical synthesis on the timescale of 10^{-5} seconds to Universal change on the timescale of 10^{18} seconds. The most relevant processes related to the RtD inquiries are those that take place on the order of minutes to years: Utterances, Episodes, lessons, lesson sequences, school days, units, unit sequences, semester curriculums, and multi-year curriculums.

For engineering education, we design on various scales. On the larger end of the scale, a team of educators and administrators might design a multi-year curriculum. Within that curriculum, an instructor might design a course on the timescale of a semester or quarter. Within the course, one might design a unit or sequence of units lasting days to months. Within a unit, one might design activities, lessons, or assignments lasting hours. Even for a given activity, one might design supporting materials such as lecture slides, demonstrations, and worksheets.

When looking at the two sites of learning, solutions to the design research question were carried out on several scales. In Making and Mapping, RtD inquiry was carried out at the curriculum level on the timescale of ten or twenty-week seminars. Within those seminars, units and activities were designed as well. However, in Explorations in Human-Centered Design, the curriculum and unit level were already designed. RtD inquiries were designed at the episode or lesson level.

The “activity” level was chosen as the unit of analysis for defining different RtD explorations to analyze in the annotated portfolio. This was done for feasibility and because this level of design for the design research question was done in both sites. In prior work, looking at the second iteration of the Explorations in Human-Centered Design course (EHCD_2), it was determined that looking at the curriculum and unit level for AP was difficult because of its large scale [21].

In addition to scale, what makes up an “artifact” is ambiguous in engineering education. In engineering education, we are designing learning

environments. So, things are being designed that go beyond physical artifacts. Rather than just focusing on a physical “artifact,” this analysis identifies the collection of examples, what it took to make it, and how the collection was used. In this work, I refer to the activity level “artifacts” that resulted from RtD inquiry as “Seeing Across Projects (SAP) Activities,” sometimes just referred to as “activities.”

Breadth Annotated Portfolio

The annotated portfolio analysis was begun with a breadth-focused portfolio and then followed by a depth-focused annotated portfolio.

Documentation Review and Identification and Selection

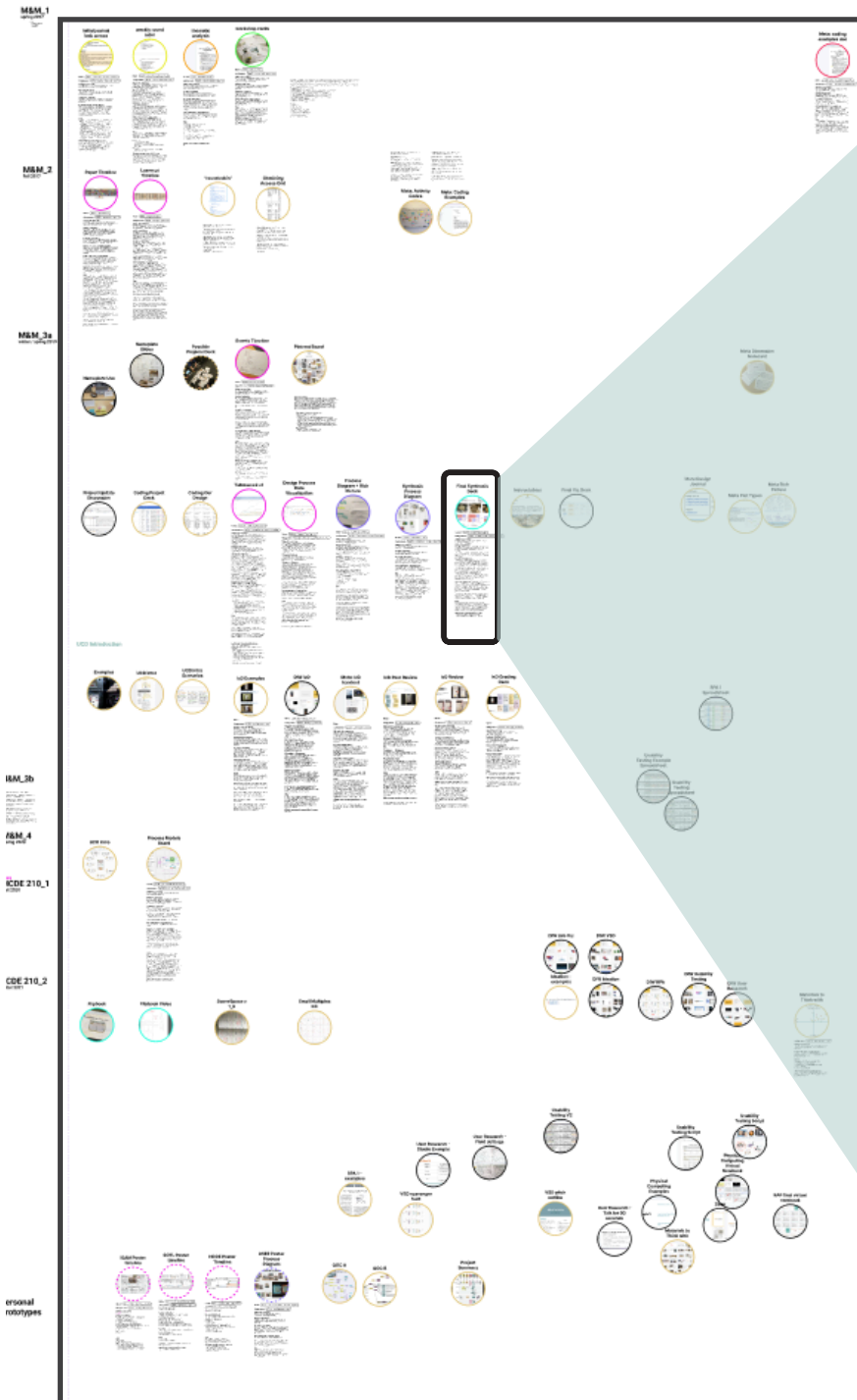
The two sites of learning described prior were used as the source of SAP activities (activity level RtD artifacts). Identification of activities began with a systematic review of documentation for the three iterations of the Making and Mapping seminar and the two iterations of the Explorations in Human-Centered Design course. Autobiographical design techniques (like [15] and [11]) were used to prototype variations on activities before and after use in these learning environments. Documentation of these “activity prototypes” was also included in the documentation review.

Documentation was reviewed course by course chronologically. Screenshots and photos of crucial information were compiled. Available documentation from each course varied but included sources such as course overviews, meeting notes and agendas, worksheets or assignment instructions, completed assignments, lecture slides, and photographs of classroom setup or activities. In addition to these sources, I took reflective notes during some of the planning and execution of SAP activities. For some learning environments, audio recordings of meeting discussions were available but not used. Notes from these discussions were used instead, as the granularity of audio transcriptions was not needed.

Representation and Annotation

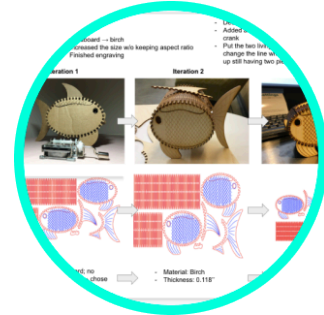
Figma was chosen as the medium for both annotated portfolios. Figma is a collaborative web application for interface design. This software was selected as the medium for representation due to

A Breadth of SAP Activities



B Breadth-Focused Annotated Portfolio for one SAP activity

Final Synthesis Deck



Name: M&M3b - Final Synthesis Deck

Assignment: M&M3b - 3 iterations of laser

Object of Learning: this RTD prototype was focused on helping students learn [interaction design]

Design Collection: this RTD prototype brings together [8] instances of [3+ iterations of a lasercut project] from [8] student designers.

there were 12 students in the course doing lasercutting work, but not everyone completed the deck (may have been absent)

Creation + Support: Students were able to build on prior documentation (process diagrams, field notes, reflections, memory, photos) to construct their diagrams. Time was given in the meetings so there was not pre-work expectation.

The instructor setup deck and created an example from student work to demonstrate what was expected.

Externalization + Aggregation: This externalization moved from representing process activities to instead representing the 3+ iterations and using those as a stand in for design decisions or changes across each iteration.

Each student represented their process on 2 slides in an individual digital deck. The first slide was visual including the 3+ iterations represented in columns left to right. Then top to bottom for each iteration a photo, design layout, and laser settings were included. Then text annotations explained why changes were made between each iteration.

The next slide had additional details for each in a text grid including time, materials, tools, software, people, resources, cost, location. For each category changes from one iteration to the other were to be noted.

Use: In M&M3b, we explored process mapping as an alternative representation style throughout the 10 week quarter. During sensemaking meeting # 10, students were given 30 min to make a final summative process diagram. Following this students each had 5 min to present (3 min to share with 2 min for questions)

What was made possible to see:

- changes between versions (iterations)
- two representations photo v.s. design file

Figure 4_2: This figure depicts the breadth-focused annotated portfolio while in progress. A) Shows a screenshot of the portfolio of over fifty SAP activities. Each activity is represented by a single image and title. Annotations were added below. B) shows an example of one SAP activity. At the top, you can see the title and a representative image of the SAP activity. Below are a set of annotations describing the object of learning, the design collection, what it took to create it, externalization and aggregation of the collection, how the collection was used, and what it made possible to see.

its capabilities and easy access. Documentation of the activities was already primarily in a digital format, making a digital medium ideal for visual analysis. The software provided nearly infinite digital space to organize representations and functionality for grouping images onto pages and “frames,” adding text annotations, and interacting through zooming and panning.

The collection of documentation was organized in Figma. As the SAP activities were identified, relevant documentation was grouped and labeled. A single image was chosen to represent each SAP activity, and each activity was named. Very brief annotations were added to each representation. These were constructed iteratively. For each activity, annotations included one or two sentences describing the learning objective, design collection, creation and support of the collection, externalization and aggregation of the examples, use of the examples, and the learning outcomes. Figure 4_2 provides an in-progress visual of the breadth-focused portfolio.

Synthesis

Annotations were grouped to identify common ideas. The synthesis resulted in a better understanding of commonalities among design solutions. The portfolio analysis resulted in many “qualities” and “attributes” of designing for ‘seeing across projects’ based learning. These attributes were synthesized broadly into a model. This model represents the general solution to the design research problem: “How might we design environments that support learning from seeing across individual design experiences?” This model and the description of two SAP activities (“ultimate particulars”) can be found in Chapter 5.

Depth-Focused Annotated Portfolio

Following the breadth-focused annotated portfolio analysis of over fifty SAP activities (RtD artifacts), a subset of these activities was analyzed in further detail through a depth-focused annotated portfolio.

Selection

As mentioned in Chapter 3, annotated portfolios of RtD artifacts typically select between four and nine artifacts to analyze. Seven SAP activities

documented in the breadth-focused AP were chosen for this analysis.

Activities were selected based on four criteria: iterations, diversity, documentation, and use. Many SAP Activities were iterations on common ideas and themes. One aim of selection was to select activities that captured common themes across the inquiries. Another aim was to choose a diverse set of activities. This included looking for activities from both sites of learning and ones that captured the breadth of features and ideas explored. The extent of documentation varied across the activities and sites of learning. A third aim was to select activities that were richly documented so that the analysis would be well-grounded. Finally, the selection also considered the use or testing of the activities. Hauser emphasizes the importance of selecting artifacts that have been “field tested” not just conceptualized [7]. Some of the activities used “autobiographical design techniques” [11, 16] as described in Chapter 3. In the context of designing for learning, these were considered prototypes and were excluded from selection.

The seven SAP activities selected were the “Nameplate Use” and “Possible Project Deck” activities from M&M3_a, the “Project Update Discussion,” “Design Process Data Visualization,” and “Design Process Diagram and Rich Picture” activities from M&M3_b, the “Design in the Wild Interaction Design” activity from EHCD_1, and the “Design Process Model Board” activity from EHCD_2. Two of these activities are fully described along with the SAP framework in Chapter 5. The others are briefly described in Chapter 6.

Representation

After the seven SAP activities were selected, they were represented in Figma. Each of the seven activities was represented by a “frame” or dedicated box of space. Multiple photos and screenshots were organized in each frame, and the seven frames were lined up horizontally next to each other on a digital page.

While many annotated portfolios in the field of human-computer interaction limit representations to one or two photos of the finished physical design artifacts, modifications were made to represent important features of the framing

A 7 SAP Activities

Nameplate Use

Project Update Discussion

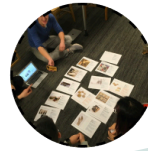
Process Diagram + Rich Picture

Design Process Data Visualization

Possible Projects Deck

Design in the Wild - IxD

Process Models Board



Depth-Focused Portfolio for one SAP Activity B

C One Annotation

What are the instances to be compared

groups

Decision: I decided to have each group have a sort of space within a space. If you think about the timeline representations each event was recorded in a common reference frame. In contrast this has 17 different reference frames.

Rationale: I thought this was a process that students might be familiar with. How science and design are different felt like a meaningful distinction to draw on in an engineering department where many of the students in the course are choosing their major.

Results (what was made possible): Seeing across within the group is prioritized over across the group. So you could zoom out and compare group to group, but it wasn't very easy to see significant details.

Its pretty easy to see that groups used different models, but seeing much else would require more time and cognition b.c. of how the representations were arranged.

Future: I have mentioned this elsewhere in annotations and have tried it in other 210 prototypes. I think there was a wasted opportunity here to leverage the many models at a beyond the group level.

Clustering the non-design models might have helped us understand types of non design processes.

mixing up design and non design could have helped see that things like the number of steps and relationship of them was variable in all models.

I wonder about an activity where you start at a small group level and then join groups until you stop noticing different things. So for example if group 1 and 2 had joined and then said ok what do we see is still true with 10 examples instead of 6.

Prototype Name: HCDE210_2 - Process Models Activity

Assignment: HCDE210_2 - unit 1 UCD introduction

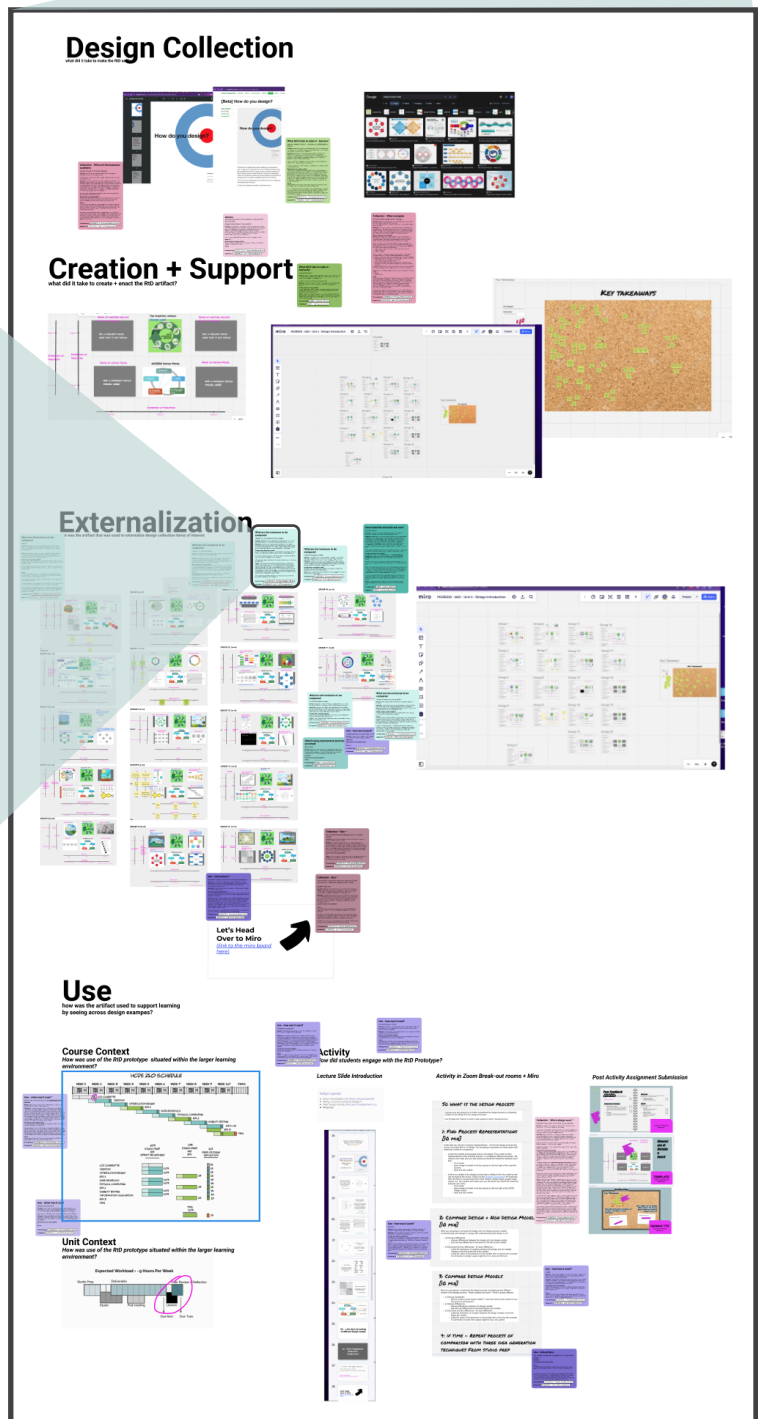
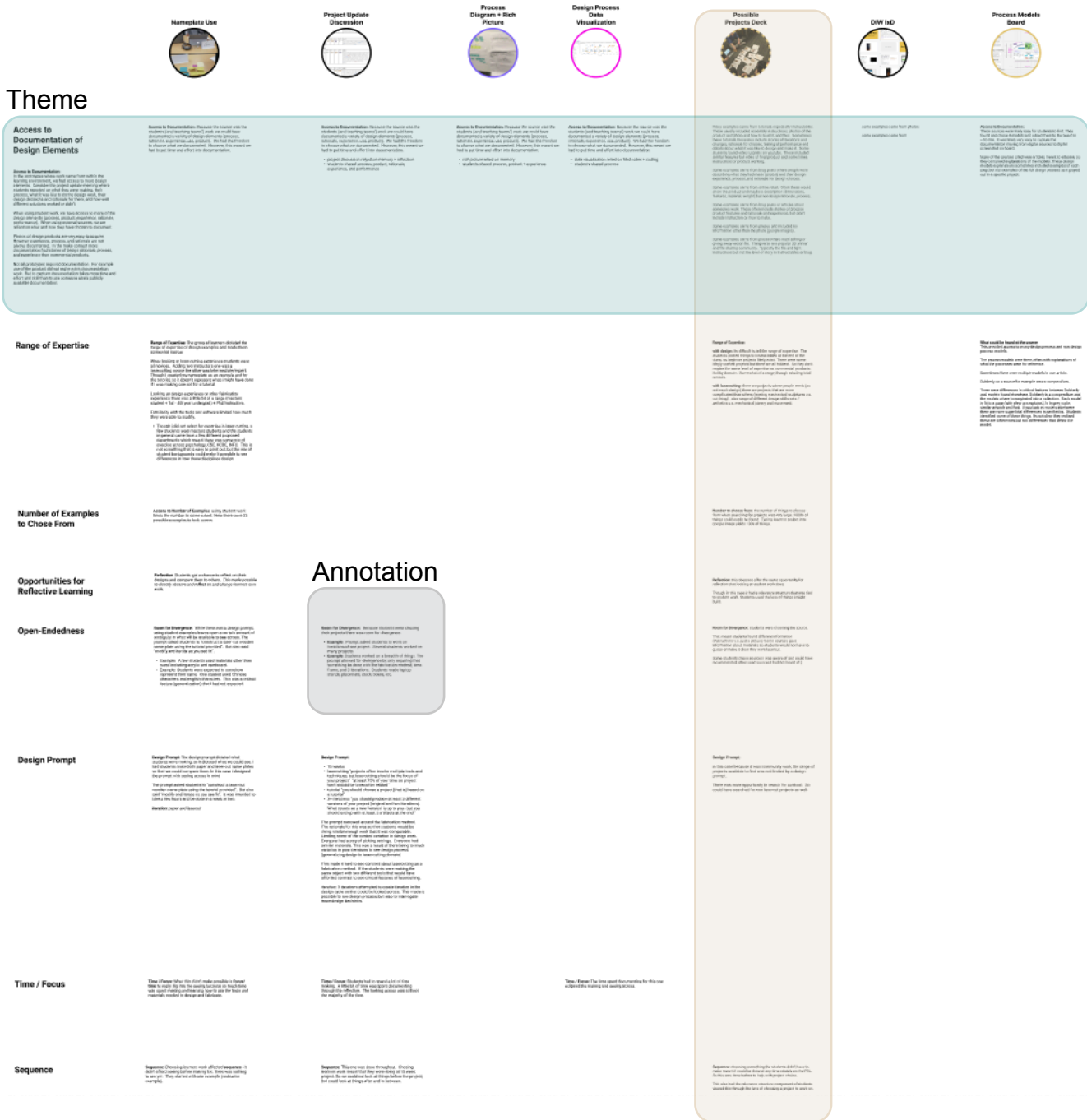


Figure 4_3: This figure depicts the depth-focused annotated portfolio analysis. A) shows the seven SAP activities represented by a single photo or screenshot. B) Shows the depth-focused annotated portfolio for the Process Model Board activity. The four categories of representation (collection, creation and support, externalization, and use) can be seen from top to bottom in bold headings. One to five screenshots or photos can be seen in each section. Annotations are contained in colored boxes next to the screenshot of the photo is annotates. C) shows an example of one annotation. The annotations include the design decision, rationale for that decision, results, and changes considered for the future.



SAP Activity

Figure 4_4: This figure depicts the visual analysis done for the three selected properties. The 7 SAP activities are listed at the top of the figure. The annotations for each activity (blocks of text) are arranged under the activity in a column. The annotations were also arranged to create rows of common themes.

of “learning activities” as RtD “artifacts.” Four categories of representations were identified from insights gained in the breadth-focused portfolio and considerations of how learning activities differ from physical artifacts. These categories were collection, creation and support, externalization, and use.

The “externalization” section most resembled the traditional annotated portfolio of a physical design artifact. This section was used for representations of the collection of externalized design examples. The “collection” section included representations of what design examples were being used and the designs’ authors. The “creation and support” section represented what it took to create the externalization of design examples. Finally, the “use” section represented how students used the examples to elicit learning. Screenshots gathered in the identification phase for the breadth-focused AP were used. One to five screenshots were selected for each section. Figure 4_3 provides an image of the portfolio for the Process Models Board SAP model.

Annotation

Next, the seven SAP activities were annotated. Annotations were used to surface design decisions, assumptions, and issues not externalized by the final artifact but that could be elicited by representations of the artifact. As described in Chapter 3, the same portfolio could be annotated in several ways. A perspective is therefore chosen to focus the annotations. The primary perspective for annotating this portfolio was “seeing-across-projects” based learning. Annotations were focused on design decisions that were intended to or had the potential to support learning by seeing across individual examples of design.

The Variation Theory of Learning (VT) was used as a lens for annotating the learning potential of different design decisions. While VT was not used to guide the design of most of the SAP activities, it was used as an analytical lens in annotations. These annotations leveraged the concept of the “enacted object of learning” to focus on what the enacted patterns of variation made possible to learn. Annotations also focused on the feasibility of the implementation of these learning activities.

As described in Chapter 3, first-person accounts provide rich annotations and holistic understanding through deep knowledge of the design rationale and evaluation [18, 19]. In this case, first-person accounts were provided for all seven activities.

A template was created to guide annotations. This template included four sections: decision, rationale, results, and future modifications. The template was copied for each annotation, and each section was filled in with a few sentences. The “decision” section described the design decision in the particular SAP Activity being annotated. Some descriptions of decisions included alternatives that were considered. The “rationale” section was used to describe the reasoning for making the decision being focused on in this annotation. Some annotations contained several reasons for the decision. The “results” section was used to note any evidence of how that decision had supported (or not supported) learning by seeing across. This is where the enacted object of learning concept from Variation theory was considered. The final field in the annotation, “future,” was used to note ways I might consider changing this particular design parameter. This section was included to provide another form of surfacing results or rationale. The annotation also had the SAP activity name and the assignment (PBL activity) it was part of. Around twenty annotations were created for each of the seven chosen activities. A visual of an annotation can be seen in Figure 4_3.

Synthesis

The synthesis of the annotations was carried out in a few stages. First, annotations were grouped by related design decisions or “features” of the SAP activities. Due to the number of decisions, three “features” seen across the SAP activities were identified for further analysis. For each of these features, values were articulated for each SAP activity. Then, annotations were spatially arranged to elicit themes. Each theme represented how the design feature had potential implications on learning or feasibility. A second iteration of annotation was carried out to ensure that annotations on each SAP activity were made where applicable. The three features, values of these features as seen across the SAPs, and potential implications of these features on learning

are articulated in Chapter 6. Figure 4_4 depicts the visual analysis used to surface themes for the three selected properties.

Framework

The variation theory of learning (VT) describes how people can learn by juxtaposing examples in specific ways. However, VT has primarily been used in non-generative learning contexts where there is a correct answer. Limited research has focused on how we apply VT in project-based learning environments. While VT was not used to guide the design of SAP activities (except in the Design Process Models Activity in EHCD_2), it holds promise as a complementary lens for supporting learning through seeing across design experiences.

The final stage of this research aligned the key aspects of variation theory with the SAP Activity model developed from the annotated portfolio analysis. The result of this alignment is a pedagogical framework to support designing ‘seeing across projects’ activities within project based learning (PBL) environments using the pedagogical lens of variation theory. This framework is described in Chapter 7.

Trustworthiness

Discussion of trustworthiness in the research through design (RtD) and the annotated portfolio (AP) methodologies is articulated in Chapter 3. There is a call in the field of human-computer interaction (HCI) for “actionable metrics for bringing rigor in critique of design research” [3]. However, there is no consensus on quality standards for RtD and AP. As the work of designers has been positioned as subjective [2], RtD is seen as closer to the interpretivist research paradigm [22]. Zimmerman Forlizzi and Evenson [22] propose a set of criteria specific to RtD, but it is not well adopted.

In evaluating contributions to ‘trustworthiness’ in this work, I consider the strategies for ensuring trustworthiness in the qualitative work laid out by Shenton [20] related to credibility, relevance, dependability, and confirmability. I also consider specific methodological standards of the

annotated portfolio method.

The use of well-recognized research methods contributes to the ‘**credibility**’ of this work. Both RtD and AP are well-established methodologies in HCI. While they have not been adopted in engineering education, the rationale for choosing these methods is articulated (see Chapter 2). Additionally, the changes made to the method to adapt it to an engineering education context are described in this chapter. An extensive description of these methodologies, as they are practiced in HCI, is provided in Chapter 3, contributing to the work’s ‘confirmability’ and ‘dependability.’ This in-depth methodological description allows the integrity of research results to be scrutinized [20]. Additionally, the level of methodological description and figures depicting analysis in this chapter provide an “audit trail” contributing to ‘**confirmability**.’

Prolonged engagement with the RtD inquiries over four years contributes to the ‘**credibility**’ of this work. Koskinen notes that more substantial research results come from RtD research programs that repeatedly investigate the same design research problem than from individual RtD research projects [9]. In this work, over 50 RtD inquiries were carried out related to the same design research area of designing for ‘seeing across projects’ based learning.

Triangulation of RtD inquiries across two learning sites contributes to the ‘**credibility**’ of this work. RtD inquiries were first carried out in the Making and Mapping seminar. Then, the same design research question was applied in the more structured environment of the introductory design course Investigations in Human-Centered Design.

Shendon describes how including background data to establish the study context allows comparisons to be made [20]. The context of the two learning environments is briefly articulated in this Chapter. In Chapter 5, the context and rationale for design choices are articulated for the two RtD activities explained in depth. This description of context helps contribute to the ‘**transferability**’ of this work.

Gaver argues that the integrity of the annotated portfolio method comes from a balance between

detailed examples of design practice and annotations articulating the issues, values, and themes that characterize the relations in the collection [5]. Multiple visuals were used for each activity in the depth-focused annotated portfolio to balance design examples and annotations.

Hauser and colleagues describe the importance of selecting artifacts for the annotated portfolio that have been field-tested, not just conceptualized [7]. In the depth-focused annotated portfolio, the seven SAP activities were chosen because of their depth of documentation and because they had been field-tested.

Finally, first-person accounts add to the trustworthiness of the annotated portfolio by providing rich annotations and holistic understanding through deep knowledge of the design rationale and evaluation [18, 19]. All RtD inquiries (SAP activities) were first-person accounts.

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Chapter 5: 'Seeing Across Projects' (SAP) Activities

Across the two learning sites, the Making and Mapping Seminar and the Explorations in Human Centered Design introductory course, over fifty learning activities were designed to answer the research question, "How might we design environments that support learning from seeing across individual design experiences?". Several common properties emerged in the annotated portfolio analysis of the breadth of learning activities, resulting in a model to describe a general solution to the design research problem. I refer to this general solution as a 'seeing across projects' (SAP) activity. This chapter describes the five elements of the Seeing Across Projects Activity Model. Descriptions of two specific SAP activities are included to illustrate different solutions within the SAP model.

Anatomy of a Seeing Across Projects Activity

Five elements make up the SAP Activity Model: engagement in design work, the capture of traces of design work, the selection and representation of examples of design work, the use of those examples to learn through comparison, and finally, the application of that learning to future design work. See Figure 5_1 for a visual representation of the model. Here, 'examples' of design work include not only the artifacts of design but also design rationale, process, experience, and performance (see Chapter 6).

Engagement in Design Work

Engagement in design work is the foundation of the SAP model. All learning activities analyzed in the annotated portfolios were built within Project Based Learning (PBL) environments where learners engaged in individual or group design work. In the model (Figure 5_1), engagement in design work is represented by two large black arrows along the bottom of the figure. The remaining elements are represented as smaller arrows on top to indicate that these activities are built on the design engagement. The two black arrows represent the design work that students engaged in before and after the SAP activity. The design work done before the SAP activity has the opportunity to be the focus of the activity and resulting learning. The design work completed after the SAP activity can benefit from the learning that takes place in the activity.

While the SAP activities analyzed in this study included learner engagement in design projects, engagement in design was done in several different ways. In some SAP activities, design engagement was designed to support the SAP activity. In other cases, the SAP activity was added to a preexisting project, and very few changes were made to the design engagement. Whether planned with the SAP activity in mind or not, the design engagement was instrumental in determining other elements of the SAP activity. Key properties of design engagement included **what** was being designed, **who** was doing the designing, what the **duration** of the design work was, and how the design work was **structured** and supported.

Capture of Design Work

The next element in the SAP model is the capture of design work. Capture refers to the process by which design work (or certain aspects of design work) is documented so that it can be represented and compared. Capture results in traces of design. The blue arrow on the far left in Figure 5_1 represents the capture of design work.

Capture was done differently across the SAP activities analyzed in this study. Key properties of the capture element included the source of the design work being captured, the extent of the capture process and training, what content to capture, when to capture design work, what method to use for capture, and who was responsible for capture.

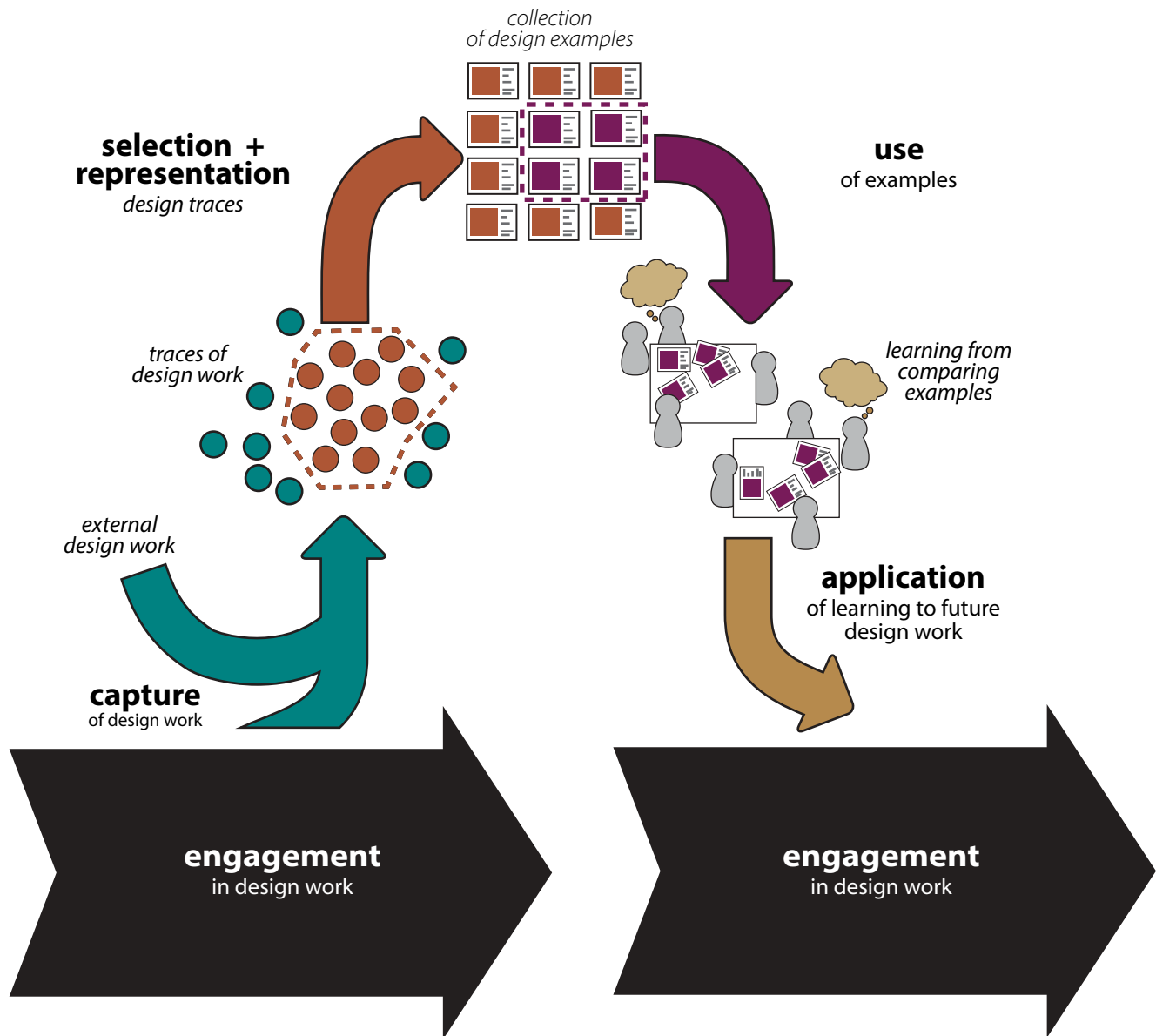


Figure 5_1: The five elements of the 'Seeing Across Projects (SAP)' Activity Model are depicted by arrows in the figure above. Engagement in design work is represented by the thick black arrows at the bottom of the figure. The colored arrows represent the four steps it takes to add an SAP activity on top of design work. The black 'engagement arrow on the left represents design work that happens before the SAP activity. The teal arrow represents the 'capture' of design work from the learner's design engagement or other sources. This results in traces of design work represented by circles. Next, the red arrow represents the 'selection and representation' of a subset of traces resulting in a collection of examples. The purple arrow represents the selection and 'use' of examples from the collection to support learning through comparison. Finally, the yellow arrow represents the 'application' of that learning toward future design work.

One key consideration in capture is the **source** of capture. This refers to what design work is the focus of the capture. In Some SAP activities, the design work of learners was chosen as the source. However, due to feasibility considerations, external design work from experts or others outside the learning environment was selected as the source in other SAP activities. The branches of the blue arrow in the SAP Activity Model (Figure 5_1) represent the choice of source. Differences in source across some of the SAP activities and the potential impact of source on feasibility and learning are reported in Chapter 6.

Another property of capture that varied across SAP activities was how **extensive** the capture process was. While there must be traces of design from which to select and represent examples, not all SAP activities included active engagement in capture from actors in the learning environment. For example, some SAP activities used traces of design work that were publicly available. Some SAP activities used the final artifact of a project, which did not require any active documentation. For these SAPs, no capture was required. In other SAP activities, much time and effort was devoted to capturing traces of design work and supporting the learning of capture methodologies.

There are many methods of capture to choose from. What **method** of capture was used is another property of capture. Different capture methods were selected to match the constraints of each individual SAP activity. Various capture methods were utilized, from photos of design products to design journals describing design activity.

Another property of capture is **when** to engage in capture. In some SAP activities, design traces were captured alongside the design work. In other SAP activities, capture was done at predetermined frequencies or when the design project was completed.

What **content** to capture was another key property of capture. Content refers to what aspects of the design work to focus the capture on. Some SAP Activities focused on the design process or learners' experience of engaging in design, while others focused on what was being designed. In some SAP activities, many things

were captured with the idea that choosing what to represent could come later. In other SAP activities, what to capture was more specific and narrow.

A final consideration within the capture element was **who** was doing the capturing. In many SAP activities, learners were doing the capture. However, in some SAP activities, the design work was captured by instructors or others external to the learning environment.

Selection and Representation of Examples

The next element of the SAP Activity model is the selection and representation of design examples from the captured traces. These examples make up a collection. This collection can then support students' learning by comparing these examples. Selection refers to the choice of what examples to include. Representation refers to how the examples are represented individually and as a collection to be compared. The process of selecting and representing design examples is represented by the red arrow in Figure 5_1.

Selection varied across the different SAP activities. Key properties of selection include who is selecting, how examples are being selected, and what is being treated as an example.

As with capture, not every SAP Activity included the active selection of examples. Sometimes, all examples were represented. What was treated as an example also varied across different SAP Activities. Some activities treated projects as individual examples, while others treated iterations within a project or engagement in design activity throughout a project as the particular examples to be represented and compared. Differences in source across some of the SAP activities and the potential impact of source on feasibility and learning are reported in Chapter 6.

Who was making decisions about the selection of examples, representation of examples, and representation of the collection of examples varied across different SAP activities. In some SAP activities, the learners made decisions about selection and representation. In other activities, the instructor made decisions, or many actors jointly made decisions.

Different representations of the individual examples and the collection of examples were used in various SAP activities. Key properties of representation included **what** content to represent, **how** to represent it, how **consistent** each representation should be, **who** was representing the examples, and how to **aggregate** examples into a collection.

What **content** to represent varied across different SAP activities. In some activities, the design process was represented, while in others, design products and critiques of those products were represented.

Another property of representation was **how** to represent the examples. Some SAP activities used physical representations like index cards, while others were represented digitally. The availability of different tools and technology shaped the representation of collections of examples in various SAP activities. Finally, information was encoded in multiple ways, including text, images, and visualizations using color and space.

Another property of representation that varied across different SAP activities was the aggregation of individual examples into a collection. Across many activities, a focus was put on how the collection could support the comparison of examples. However, methods for doing this were diverse. Some SAP activities more strongly dictated how examples would be compared through a fixed organization of examples. Other SAP activities represented the examples so that students could organize and compare examples in their own ways.

Use of Examples

Once a collection of design examples is selected and visualized, those examples can be used to elicit learning through comparison. The element “use” refers to learner engagement in comparing or looking for patterns among the examples to support learning a particular concept. The result of using the design collection is learning from comparing design examples. “Use” is represented by the purple arrow connecting design collection and learning in the top right.

The use of visualized collections of examples varied across the SAP activities studied. Key properties of the ‘use’ element of the SAP model included selecting what examples to use, how to use examples, and who is using examples.

There was a **selection** process here as well. In some SAP activities, students could engage with the whole collection. In other SAP activities, students looked at a subset of the collection.

Another key property of use was the **level of structure**. Some SAP activities were very structured, giving students specific instructions on what and how to compare examples. Other SAP activities gave students autonomy to make sense of how they wanted or even just exposed them to the collection with little specific engagement at all.

Another property of use was who was using the examples. One consideration of who was if learners were engaging in the use of the collection individually or in groups.

Application of Learning to Future Design Work

The final stage of the SAP model is for learners to apply what they have learned from using the collection to their future design work. This is represented in Figure 5_1 by the yellow arrow on the far right connecting the activity and the future design work. None of the SAP activities had explicit scaffolding around how students might apply what they learned in the activity to future design work outside of the learning environment. However, the sequence of some SAP activities positioned the activity before particular design projects so that learning outcomes could be immediately applied to a project later in the course.

SAP activities

The following two sections describe two different SAP activities to illustrate how these activities answered the design research question differently but still fit within the general solution of the SAP activity model. Each section begins by articulating the design constraints that lead to certain decisions about elements of the SAP activity. Next, the context for the activity is

described, including the learning environment, the learners, and the design work the students were engaged in. Finally, the sequence and each element of the SAP framework are described.

Design Process Data Visualization

Several SAP activities explored data visualization as a method to represent and make sense of design examples. In particular, visualizations of types of design activity over time were used to represent and compare examples of students' design processes. Several Making and Mapping seminars used iterations of these design process timelines. The Design Process Data Visualization SAP Activity took place in the third iteration of the Making and Mapping (M&M_3b) seminar. This activity was the final iteration of creating and using design process timelines. This last iteration also leveraged alternative visual representations.

Design Problem

All the SAP Activities were solutions to the design research question, "How might we design environments that support learning from seeing across individual design experiences?". However, each SAP Activity represents a unique response to particular design opportunities, problems, and constraints. The Design Process Data Visualization SAP Activity was a result of the aims of the Making and Mapping Seminar, as well as particular opportunities and challenges that surfaced in past SAP Activities.

The learning environment in the Making and Mapping seminar was framed around the idea that engaging students as researchers studying their own design work was one possible solution to the design research problem. The SAP activities in the Making and Mapping seminars were inspired by ideas of co-research and autoethnographic practices and engaged students in data collection and analysis. The Design Process Data Visualization SAP fit within this broader design solution, leveraging qualitative data collection resembling auto-ethnographic field notes, developing and using qualitative codes, and data visualization to support analysis.

One criterion that influenced this particular design solution was the learning objective of helping students recognize the features of a good design process. Because a good design process leads to a good design product, understanding the features of the design process is a vital learning aim in engineering education. The focus on the design process in this SAP activity influenced many choices about the capture, representation, and use of design examples.

A particular inspiration for this SAP Activity was Atman's design process teaching activity used to support students in understanding patterns in different quality design processes through visualization of design process timelines [1]. In this activity, students compare six timelines representing the design process of three freshmen and three seniors with low, medium, and high-quality designs. Given that these representations help students understand patterns in higher-quality design process, what additional learning might be possible if students can represent and compare their own design processes in this type of visualization?

Access to technology and tools provided design opportunities and limitations in many SAP activities. In the second Making and Mapping seminar (M&M_2), students constructed an analog timeline representation using Post-it notes. This representation can be seen in Figure 5_2. This particular representation was inflexible in that we could not quickly re-visualize the same information in different ways. For example, post-it note color was used to represent who's design activity was being represented. If we wanted the color to represent the kind of activity instead, the representation would need to be re-created by hand. This constraint drove a design question of how to collect and represent traces more flexibly to explore different ways of visualizing our data. In contrast to the analog timelines created in the M&M_2 seminar, the Design Process Data Visualization SAP Activity explored software that might allow for flexible exploration and revision of different kinds of visualizations.

Context

The Design Process Data Visualization SAP activity occurred in the second quarter of the

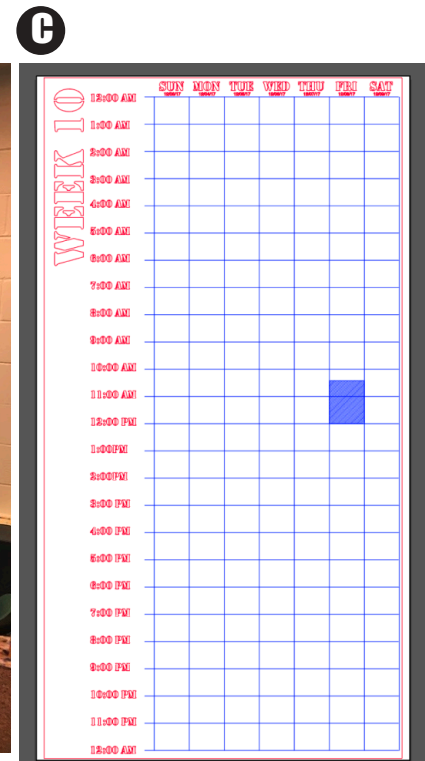
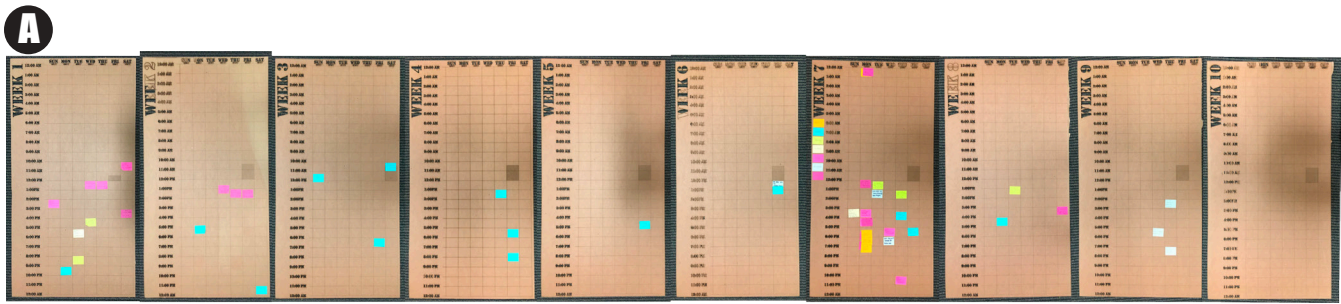


Figure 5_2: This figure depicts a prior iteration of the Design Process Data Visualization SAP activity from the second iteration of the Making and Mapping seminar (M&M_2). Item (A) is a photo of the physical timeline visualization created by a series of cut poster boards. One poster board represented each of the ten weeks in the quarter. Time was marked out on the boards in days left to right and hours top to bottom across the bottom. Post-it notes were used to represent design activity. A different color of note represented each student (designer). Item (B) is a photo of the room setup before a weekly meeting. The timeline is leaning against the wall. Item (C) is the digital file used to create each poster board.

third Making and Mapping seminar. This was taught in the spring of 2019 (M&M_3b). The making and mapping seminar was led by two graduate students, myself and another graduate student. Twelve of the 21 students who had participated in the first quarter of the seminar were invited to participate in the second based on interest and availability. All twelve students were undergraduates who were novices in laser cutting. Nine students were in their first two years of study, and the other three were in their third year or greater. The students came from different declared or intended majors, including human-centered design, computer science, informatics, and psychology.

Student Design Work

The Design Process Data Visualization SAP activity was part of a 10-week design sprint. In the second ten-week quarter of Making and Mapping (M&M3_b), students were asked to engage in individual personal design projects using the maker spaces on campus. The project guidelines were created for the seminar with the idea of supporting seeing across in mind. Students were given three project criteria and were otherwise free to choose what to make and how to make it.

First, students were required to complete a project that utilized laser cutting as the primary

tool or fabrication process. Past seminars had not narrowed to a particular tool or domain of making, and it was difficult to compare students' work because significant context was needed to understand similarities across fabrication domains. Narrowing to the fabrication technique of laser cutting was chosen to ensure more commonality in how students described their design process while still leaving room for students to explore different kinds of projects that interested them. Next, students were to base their work on a tutorial on Instructables (<https://www.instructables.com/>), a popular project tutorial website. The rationale for this requirement was to help students pick a project that would be scoped for a beginner to get started on without additional support. Finally, students were asked to create at least three iterations of their project. This requirement was used to ensure that students were engaging in some design decisions by

starting with replicating someone else's design and using that to inspire modifications.

Each student worked on a different personal project throughout the ten-week quarter. The work of one student can be seen in Figure 5_3. We will refer to this student using the pseudonym Karen. Each photo in Figure 5_3 is drawn from Karen's documentation and represents various design work throughout the project. Karen created a wooden tea holder to organize individual tea bags. Karen started her project with a tutorial from Instructables (see Figure 5_3a). She had trouble getting the file from the tutorial to work and came to office hours for help. Karen and the instructor (myself) decided it would be easier to create a new file to cut pieces for the box than to fix the old one. We sketched how to create a wooden box that used the press-fit tabbed joinery technique (see Figure 5_3b). In pursuing three

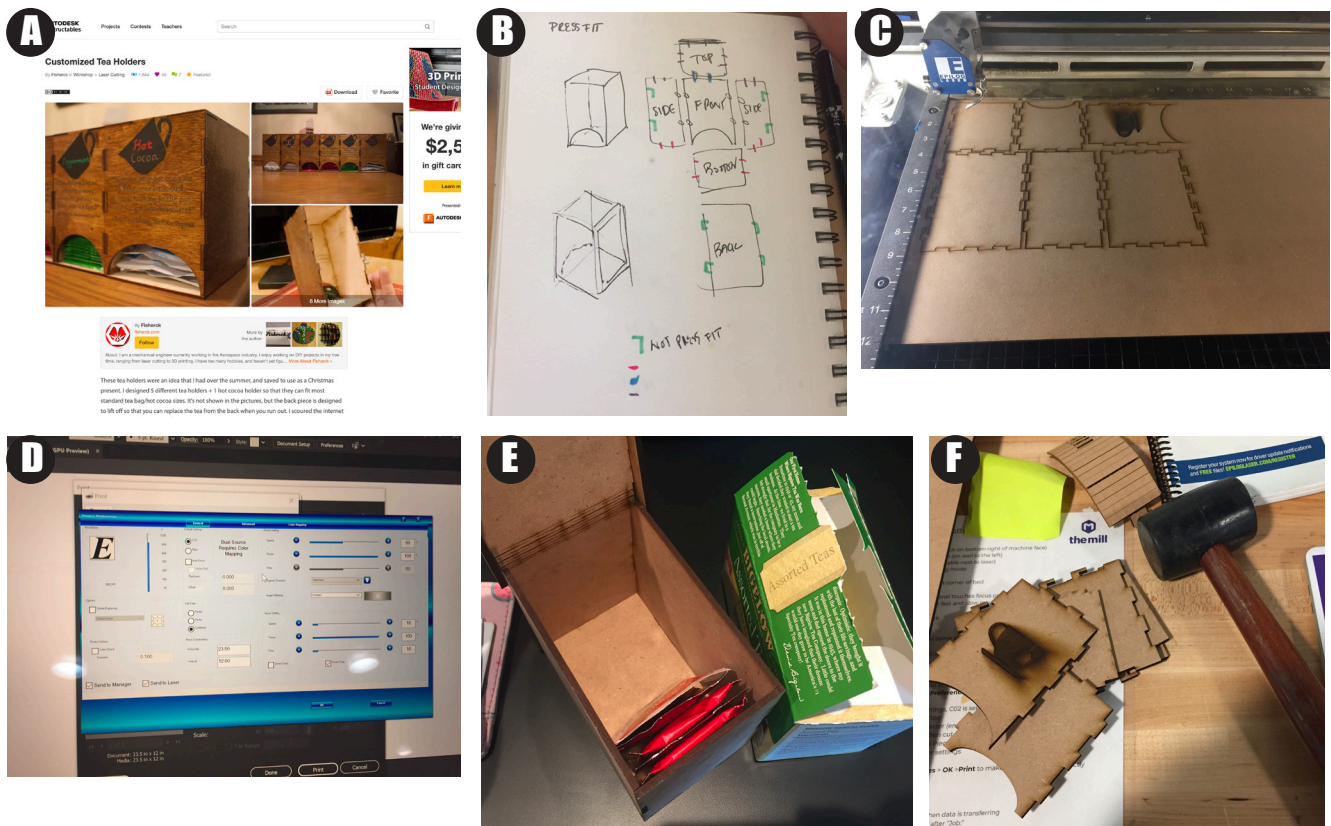


Figure 5_3: In this figure, six images are pictured to represent different activities learners engaged in as they carried out their design work. These pictures come from one student's project documentation. Item (A) shows the wooden tea holder tutorial that Karen chose to use for her project. Item (B) is a photo of a sketch in Karen's notebook used to think through how to cut each side of her tea box using the tabbed joinery technique. Item (C) is a photo of MDF material in the bed of a laser cutter just after Karen finished cutting it. Item (D) shows a photo of the settings Karen adjusted before cutting her material. Item (E) is a photo of Karen testing how well her tea box works by adding and removing tea bags. Finally, item (F) shows pieces of cut wood for each side of her box. The rubber mallet pictured was used to hammer the pieces into place during assembly.



Figure 5_4: This figure depicts the three iterations of Karen's project, a box for holding and organizing tea bags. A front and back view of the first tea holder is pictured on the far left. This replicated the design from the tutorial pictured in Figure 5_3A. The middle two pictures show a front and back view of the second version of the tea box. Karen changed the speed and power settings on the laser to try to get a less charred appearance on the tea image. She also added a hole to the back to use as a handle and reduced the number of press-fit tabs for aesthetic reasons. A closed and open view of the final version can be seen on the far left. In this final version, Karen explored a different laser-cutting technique called a "living hinge." The technique creates flexible sections in a material by cutting specific patterns of holes.

iterations, Karen engaged in setting up the laser cutter with appropriate speed and power settings for her material (Figure 5_3c), cutting pieces of wood (Figure 5_3d), and assembling those pieces (Figure 5_3f). After assembly, Karen tested how well each version worked (Figure 5_3e) to drive any needed modifications in the next version.

Karen's three iterations of the tea holder can be seen in Figure 5_4. A front and back view of the first tea holder is pictured on the far left. This was a replication of the design in the tutorial. The middle two pictures show the second version's front and back view. Karen changed the speed and power settings on the laser to try to get a less charred appearance on the tea image. She also

added a hole to the back to use as a handle and reduced the number of press-fit tabs for aesthetic reasons. In the final version, Karen explored a different laser-cutting technique called a "living hinge." The technique creates flexible sections in a material by cutting specific patterns of holes. Karen used a box maker web application to create a vector file to cut based on the provided dimensions. She then added the tea graphic used in previous versions. An open and closed version of this final box can be seen in Figure 5_4 on the far right side.

The Seeing Across Projects Activity

While the Design Process Visualization SAP Activity represents a unique instance, it can be described using the SAP Activity model. The following section describes the overall sequence of the SAP elements, followed by a description of how this particular SAP captured design work, represented examples, used design examples, and applied learning to future design work.

Sequence

In this SAP Activity, the capture, representation, and use of design examples were repeated in several cycles throughout the ten-week quarter. Design work was captured individually over the ten weeks through journaling and logging. During the second half of the quarter, examples were represented through qualitative coding and a data visualization dashboard. In the weekly meeting, the dashboard representation was iteratively updated and used to compare examples.

The twelve students and one instructor (myself) engaged in design work throughout the ten-week quarter. While doing their design work, participants documented their activities in a digital journal called a “design notebook.” Participants were instructed to use their notebooks to log their data in a collective database weekly.

As students were doing and capturing design work individually, the weekly seminar meeting was used to represent and use examples. During the first four weeks, the meeting was used to practice developing and applying qualitative codes. Students iteratively developed and applied codes to their design work during the next five weeks.

During the week five seminar meeting, students developed codes in groups. Each group was assigned a different topic: location of design work, design projects, artifacts used in design projects, and design activity types. Groups were asked to generate questions they might want to answer by analyzing their log data. They then developed codes, created a code book, and applied these codes to the logs of all student work up to that point and shared their codes with others. During the week six seminar, these groups analyzed their codes and documented what they noticed.

During the next three weeks, coding and analysis focused on the location of design work and the design activity type codes. A data visualization dashboard was used to support comparing examples. During the week seven seminar meeting, students were shown several visualizations focused on their location data. After discussing the visualization as a class, students individually refined their codes and took time to code this past week’s log data. Then, at the end of the meeting, students viewed the updated visuals and commented on any changes. During the week eight meeting, students repeated the activities from the prior week: To view and discuss visualizations, update inconsistent or missing codes, and look at the visualizations again. Then, the second half of the meeting was used to refine and code log data for the design activity types category. During the week nine meeting, the same process was followed. Half the meeting was spent viewing a new dashboard, visualizing the design activity data, discussing and refining codes, and then viewing the visualizations again. During the last half of the meeting, three groups of students each used a particular dashboard visualization to discuss, compare, and draw insights.

Source and Capture of Design Work

A key learning objective in this SAP Activity was to understand the characteristics of a good design process and to be able to recognize characteristics and patterns in one’s own design process. As such, the source of the design traces was students’ work on their ten-week design projects. The capture of this design work was focused on the students’ design process.

In this SAP Activity, students captured traces of their own design activity through journaling and logging. Journaling was a documentation practice that was inspired by ethnographic field notes. It was used and refined in all three iterations of the Making and Mapping seminar. Students were asked to use the time outside of the seminar meetings to work on their projects. As they completed project work, they were also asked to create a journal entry for each period they spent working on their projects. Each student had a separate digital document file stored in the shared Google Drive used in the seminar. Journal entries were added to this document throughout the quarter.

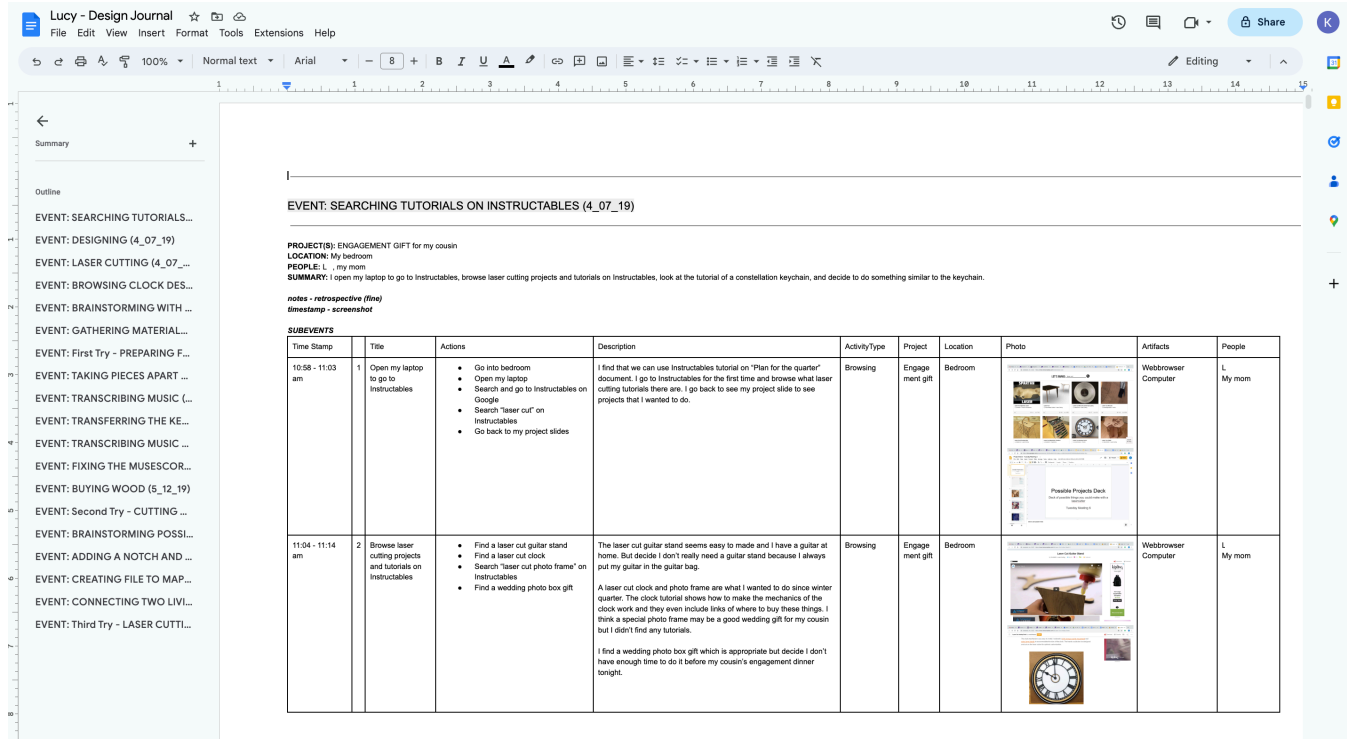


Figure 5_5: This figure shows a screenshot of one student's digital design journal. The image shows the beginning of one event entry. On the left side is a list of the events this student (Lucy) recorded over the duration of her project. The header at the top of the page contains the projects she worked on during this work session, the location, who was involved, and a brief summary of the event. In the body of the journal entry, Lucy recorded sub-events (also called activities) in a table format, each row representing a sub-event. For each sub-event, Lucy recorded the start and end time, title, list of actions, description, type of activity, project being worked on, location, descriptive photos, artifact involved, and people involved.

Journaling in this SAP activity was the result of lessons learned from journaling in prior SAP activities. Journaling was a practice that took significant effort and time for students to both learn and do. Iterations of this practice aimed to make it easier to execute and less disruptive to the student's engagement in design work. During the prior quarter (M&M_3a), students practiced different note-taking methods. This included interviewing each other to uncover details that should be recorded and photo journaling practices that would allow them to quickly capture time stamps and traces of activity while working.

At the beginning of the quarter, students were asked to follow a suggested **journaling** practice for the first four weeks. After that, they were encouraged to modify the practice if they wanted to do so. Students were asked to timestamp (through photos, screenshots, or handwritten times) and jot down brief notes during their activity. Then, students were asked to go back after their activity and write up an account in more

detail. It was suggested that students create a bullet point timeline of what happened, add photos, fill in descriptions for each bullet, and add the event header information. The instructor (myself) provided an example journal entry using her design project activity. The header included a title and description of the project iteration worked on, the activity's location, the people involved, and a summary of the event. The first entry in one student's journal can be seen in Figure 5_5.

The second method used to capture design traces was for students to use their journals to create **log entries** of their design activity in a shared relational database. The purpose of this second step of documentation was to standardize the documentation of each student into a common form that could be easily visualized.

These coded log entries divided design work into "events" and "activities." Events were defined as the largest grain size of log data. The example of events provided to students was "went to the

ID	Designer	Event	Start Time	End Time	Duration	Summary	Actions	Description	Projects	Activity Type
208	ZZ - ...	ZZ - Coming to CoMotion lab	5/6/2019 3:30pm	5/6/2019 3:57pm	27	After getting the d...	Go to the lab f...		Phone stand V	
209	KS - F...	KS - FABRIC STORE TRIP (5_07_19)	5/6/2019 3:30pm	5/6/2019 4:00pm	30	travel to fabric store	bike to fabric s...	Biked to fabric sto...	Monkey Jacket	Transportation
210	KS - F...	KS - FABRIC STORE TRIP (5_07_19)	5/6/2019 3:25pm	5/6/2019 3:30pm	5	look up route to fa...	look up route t...	looked up route to...	Monkey Jacket	info gather - mapping route
211	KS - F...	KS - FABRIC STORE TRIP (5_07_19)	5/6/2019 3:14pm	5/6/2019 3:15pm	1	called fabric store	called fabric st...	Called pacific fabr...	Monkey Jacket	info gathering - call fabric s
212	KS - F...	KS - FABRIC STORE TRIP (5_07_19)	5/6/2019 3:09pm	5/6/2019 3:14pm	5	looking up fabric s...	Looking up fab...	I knew that the no...	Monkey Jacket	info gathering - fabric store
213	SF - ...	SF - Cutting + Prototyping Front Panel	5/6/2019 11:04am	5/6/2019 11:25am	21	Cut out second fro...	Cut front_pane...	Cutout second fro...	Front Panel V2	Laser Cutting, Prototyping
214	SF - E...	SF - Editing Front Panel	5/6/2019 10:58a...	5/6/2019 11:04am	6	Editing front panel...	Centered spea...	Centered speaker...	Front Panel V2	Designing File
215	SF - ...	SF - Cutting + Prototyping Front Panel	5/6/2019 10:42a...	5/6/2019 10:58...	16	Cutout front_pane...	Cut out iteratio...	Cutout front panel...	Front Panel V2	Laser cutting, Prototyping
216	SF - E...	SF - Editing Front Panel	5/6/2019 10:10am	5/6/2019 10:42...	32	Added aux input c...	Used measure...	Referencing meas...	Front Panel V2	Designing File
217	KB - ...	KB - Researching Box Makers (5/5/19)	5/5/2019 10:28...	5/5/2019 10:46...	18	Googling "lasercut...		I decided to try g...	Teaholder	Researching
218	KB - ...	KB - Researching Box Makers (5/5/19)	5/5/2019 10:26...	5/5/2019 10:28...	2	Googling "lasercut...		I then decided to...	Teaholder	Researching
219	KB - ...	KB - Researching Box Makers (5/5/19)	5/5/2019 9:44pm	5/5/2019 10:26...	42	Googling "Laser c...		I had some time a...	Teaholder	Researching
220	ZZ - ...	ZZ - Revise the work with Kathryn	5/5/2019 6:09pm	5/5/2019 7:43pm	94	talk to Kathryn for ...	make revising ...	I have some issue...	Phone stand V	revise
221	LL - T...	LL - TRANSCRIBING MUSIC ON MUSCSCORE AND	5/4/2019 7:07pm	5/4/2019 7:12pm	5	Text Kathryn for h...	*Text Kathryn t...	Text Kathryn a scr...	Hand crank mus	Texting Kathryn for help
222	LL - T...	LL - TRANSCRIBING MUSIC ON MUSCSCORE AND	5/4/2019 2:04am	5/4/2019 2:37am	33	Finish writing 10 m...	*Finish writing ...	Finally finish 10 m...	Hand crank mus	Finishing writing 10 measur
223	LL - T...	LL - TRANSCRIBING MUSIC ON MUSCSCORE AND	5/4/2019 12:57am	5/4/2019 2:03am	66	Finish writing 5 m...	*Finish writing ...	Get 5 measures d...	Hand crank mus	Finishing writing 5 measure
224	LL - T...	LL - TRANSCRIBING MUSIC ON MUSCSCORE AND	5/4/2019 12:01am	5/4/2019 12:56...	55	Start to write note...	*Start to write ...	Download MuseS...	Hand crank mus	Starting to write notes usin
225	LL - T...	LL - TRANSFERRING THE KEY AND EXPERIMENT V	5/3/2019 11:43pm	5/3/2019 11:58p...	15	Get ready to write ...	*Find a piano v...	Find a piano video...	Hand crank mus	Getting ready to write shee
226	LL - T...	LL - TRANSFERRING THE KEY AND EXPERIMENT V	5/3/2019 3:11pm	5/3/2019 3:30pm	19	Try to figure out th...	*Cut out the un...	Kathryn suggests ...	Hand crank mus	Trying to figure out the rhyt
227	CX - ...	CX - Test my first clock stand and redesign	5/3/2019 2:55pm	5/3/2019 3:10pm	15	Test my second ve...		Test my second v...	Clock stand	Troubleshooting
228	LL - T...	LL - TRANSFERRING THE KEY AND EXPERIMENT V	5/3/2019 2:50pm	5/3/2019 3:10pm	20	Discover why the ...	*Discover why ...	Discover the teet...	Hand crank mus	Discovering why the music
229	CX - ...	CX - Test my first clock stand and redesign	5/3/2019 2:48pm	5/3/2019 2:55pm	7	Went back to hom...		Went back to hom...	Clock stand	Transportation
230	CX - ...	CX - Test my first clock stand and redesign	5/3/2019 2:40pm	5/3/2019 2:48pm	8	I show my work t...		I show my work t...	Clock stand	communication - chatting

Figure 5_6: This figure shows the log entries that students made in a collective relational database application called Airtable. Each row in the table represents a sub-event (activity) entry from a designer. Each column contains information about that entry including the designer, event name, start time, end time, duration, text summary, and project. This same database was updated with new entries (rows) as students continued their design work each week. Qualitative codes for each entry were stored in additional columns as they were developed and the entries were coded.

maker space to buy materials and cut something on the laser cutter.” Activities were defined as sub-events and the grain size of interest for representation and comparison. For the prior event, examples of activities provided to students included “walked over to the maker space, got out my material, edit my file, cut three sheets of wood, assembled my wood, took a picture, cleaned up material, left maker space.”

Students logged data for their own project work. This was intended to be done after each design session or at least weekly. Students were not always prompt at logging their design events, leading to the reallocation of time during the weekly meeting for adding entries to the database. The log data was entered and stored in a web-based application called Airtable. Airtable is a cloud relational database with a user interface resembling a spreadsheet to make it more accessible to non-technical audiences. The structure of the base was set up by the instructor (myself), and students were trained on how to log their event and sub-event (activity) data into the

sheet during the first quarter of the Making and Mapping seminar (M&M_3a). A screenshot of the database can be seen in Figure 5_6a.

Selection and Representation of Design Examples

The next element in the SAP model is the selection and representation of design examples from the traces. In this case, all of the log data was to be used as examples of design activities, so no selection of particular examples was made. This was due to the goal of observing the design process. If we only represented some design events, we would have been unable to see patterns in the process across the whole project. Certain students’ traces could have been selected, but that would have made it difficult for all students to reflect on their own design process.

The individual design examples were represented in two stages for this SAP activity. The first stage was the representation of each piece of log data through the development and use of qualitative codes.

During the first four weeks of the quarter, students learned how to develop and apply qualitative codes. Then, groups of students created qualitative codes on four different topics. Due to the difficulty and time-consuming nature of the coding, only two of the four code topics were refined and utilized in the visualizations: location of design activity and design activity type. As students developed their coding schemes in groups, they practiced coding their own logs as well as the log data of other students. Once the two code sets were chosen, students coded their own data iteratively during the last four weeks of the quarter. The final code books and the coding were done in the shared Airtable database, as seen in Figure 5_6.

The instructor (myself) engaged in additional code development for both the 'location' and 'type' of design activity code topics. This was not initially planned but was decided after seeing students' difficulty with code development and application on design data. I wanted to give students the freedom to develop their own codes so that the representations would represent their interpretation of the design process. However, I was worried that the difficulty of developing and applying codes would interfere with the ability to see patterns. So, I created an extra set of codes and coded students' log data.

The last stage of representation was to visualize all of the coded log data so that patterns across design activities, location, time, and different designers could be more easily seen and compared.

The visualizations were created by the second instructor, another graduate student with data visualization expertise. Several visualizations were created using the same data to help students see different patterns. These visualizations were created in a data visualization software called Tableau. This is software the department uses in other courses, so students were likely to have been exposed to it in prior courses or might see it in future courses. This software allowed for the creation of an interactive dashboard that housed several different visualizations that could be viewed and filtered. The Tableau software also allowed for quick updates to the visualizations as

students continued to add more log data each week to document their continuing design work.

Two dashboards were created and used during the seventh, eighth, and ninth week of the quarter. The first dashboard was used for two weeks and focused on location, time spent, and the number of events and subevents recorded. This dashboard included a total of nine visualizations. Six versions of treemap visualization were used to visualize where designers were spending their time. A scatterplot was used to plot each student's total number of recorded events and subevents, a bar graph was used to plot students' total time working on their projects, and a line graph was used to show the total running time spent by each student.

The data visualization dashboard used during the week nine meeting had three different groups of visualizations. The first group was activity timelines. These plotted time along the x-axis and designers along the y-axis. Areas of activity were colored in, and the activity type was represented by color. Five versions of this type of visualization were used in the dashboard. One of these visualizations can be seen in Figure 5_7a.

The second visualization group was a stacked bar graph of activity. This was another way of viewing the same data by looking at the total time spent on different design activity types. The bar height (y-axis) represented the total time spent. Each designer was represented by a vertical bar arranged along the x-axis. For each student, the bar was broken down into chunks colored to represent each activity type. Four versions of this type of visualization were used in the dashboard. One of these visualizations can be seen in Figure 5_7b.

The last visualization group was a treemap of design activity. Here, the time spent on activities was totaled across all designers. Volume was used to represent the total time spent on different activities. Color and space were used to represent the hierarchy of codes and sub-codes related to design activity. Two versions of this type of visualization were used in the dashboard. One of these visualizations can be seen in Figure 5_7c.

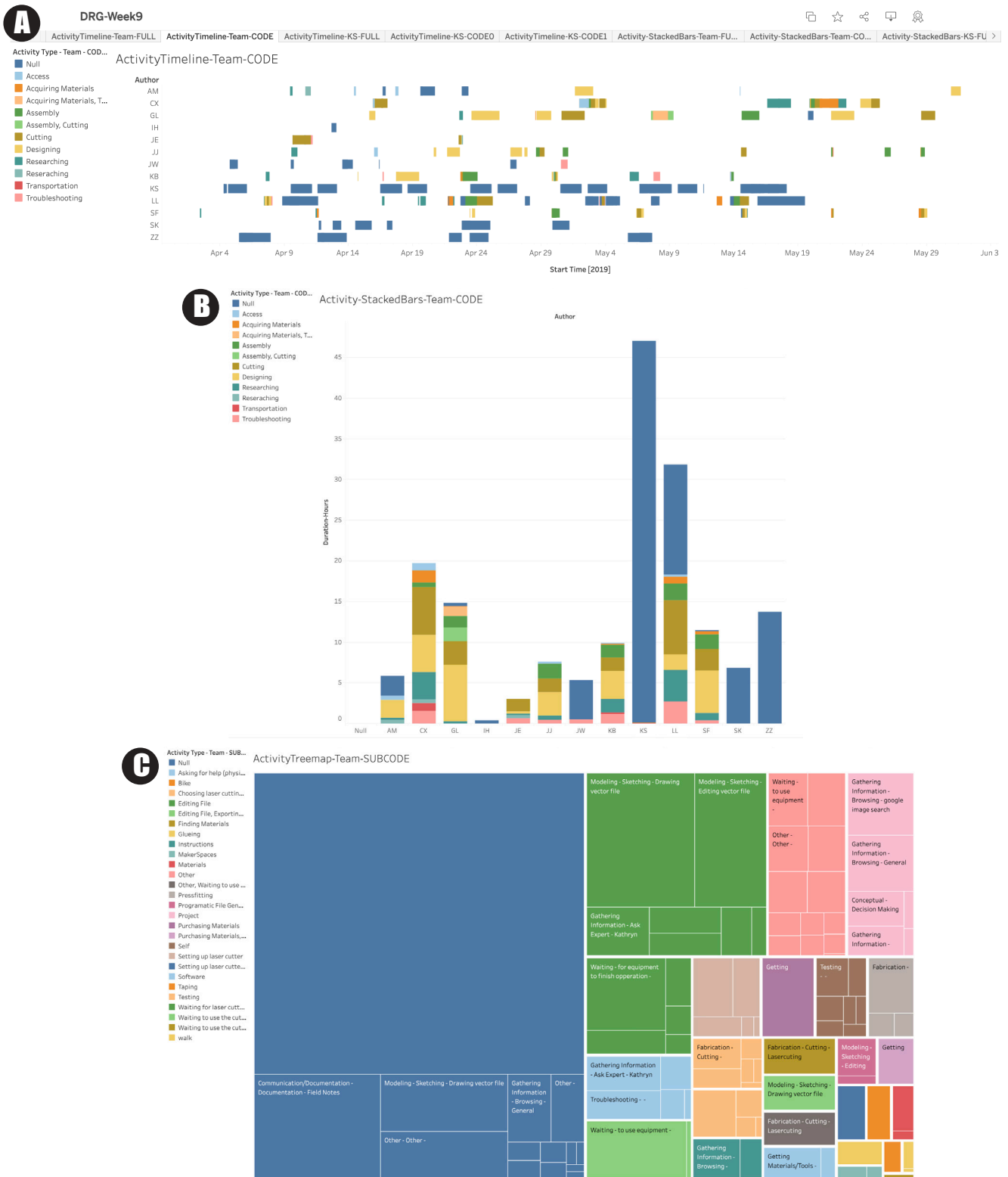


Figure 5_7: In this figure, three of the data visualizations from the second interactive data dashboard are depicted. Item (A) depicts a visualization of the designers' (both student and one instructor) design activity in the form of a timeline. Time is plotted along the x-axis, and designers along the y-axis. Rectangles represent periods of activity for each designer and are colored according to the type of design activity. Item (B) provides an alternate view of the same data through a stacked bar graph of the students' design activity. The bar height (y-axis) represented the total time spent doing project work. Each designer was represented by a vertical bar arranged along the x-axis. Like the first visualization, color is used to represent different kinds of design activities. Finally, item (C) depicts a treemap visualization of the same data. Volume was used to represent the total time spent on different activities. Color and space were used to represent the hierarchy of codes and sub-codes related to design activity.

Use of Design Examples

As described in the sequence section, data visualization dashboards were used multiple times during the seminar meeting in the seventh, eighth, and ninth weeks of the quarter. This section will focus on the use of the second data visualization dashboard in the week-nine seminar meeting.

The 80-minute meeting was divided into two parts. During the first fifty minutes of the meeting, students repeated the activity from prior weeks of viewing the data visualization dashboard, refining and updating codes, and then reviewing the dashboard. During the second part of the meeting, students worked in groups to analyze visuals through comparison.

In the first part of the meeting, ten minutes were spent viewing the dashboard on the projector. Students also had access to view the dashboard on their own laptops. Each of the three visualization types was explained, the different versions of each type were shown, and there was some open discussion about any gaps in data. Then, students were given thirty minutes to individually update their log data to ensure it was complete and as consistent with other students as possible. Students worked individually on their laptops, updating the shared database and asking questions as needed. Finally, the last ten minutes were spent viewing the updated visualizations and discussing any noticeable changes.

During the last part of the meeting, students worked in three teams. Each team had three students and was assigned a visualization type from the data visualization dashboard (timeline, stacked bar, or treemap) to analyze. Recall that each visualization was a different means of looking at the same log data of coded design activity types. Students were given twenty minutes to work in teams and then shared what they learned with the whole group.

The group work was guided through instructions in a shared digital slide deck. The students also used this deck to document their responses. The first part of the exercise asked students questions to guide their analysis and comparison of the visualizations. This included questions such as what relationships can we see in this visualization, how does this visualization help us think through

the questions we initially posed about design activity, and are there any interesting patterns we can find through this visualization? The second part of the exercise asked students to focus on one of the design activity sub-codes (for example, cutting or drawing a vector file). One student was asked to describe their recent experience with that activity in detail. Then, the group walked through a series of questions that helped them compare the visualized data to the thick description they had just documented. Finally, each group was asked to consider and draw an alternate visualization to represent their data.

Application of Learning to Future Design Work

While students were documenting their activity throughout the quarter, the use of the visualized collection of design activity occurred near the end of their projects. This left little chance for students to apply what they had learned about the design process to their current project. The hope was that students would apply their learning to future design work outside the Making and Mapping seminar.

Design in the Wild - Interaction Design Activity

Design in the Wild (DIW) was a series of seven SAP activities in the Explorations in Human-Centered Design course taught in the autumn of 2020 (EHCD_1). In each of these SAP activities, students selected examples of designs they were familiar with in their everyday life outside of the classroom, critiqued those designs using principles they were learning in the course, represented those designs and critiques on a slide in a digital slide deck, and then compared examples in small breakout groups during the weekly fifty-minute lecture.

Each activity was part of a different unit in the course and utilized concepts being taught as part of that unit. These covered topics related to interaction design, ideation, value-sensitive design, user research, usability testing, and information visualization. Two of the activities were

focused on value-sensitive design in the context of a writing assignment that students iterated on three times throughout the quarter.

The DIW activity for the second unit, interaction design, was used in the in-depth annotated portfolio analysis and is described in detail in this section.

Design Problem

Like the Design Process Data Visualization SAP activity, the Design in the Wild SAP activity was a unique solution to the design research question of “How might we design environments that support learning from seeing across individual design experiences?”. While the whole learning environment of the Making and Mapping seminar was dedicated to learning through comparing examples, the EHCD course was designed using project-based learning (PBL) pedagogy. Its primary goal was to introduce students to different topics in user-centered design by engaging them in short one-week design sprints. In this case, SAP activities were constrained by the pre-determined goals and requirements of the rest of the course.

The series of Design in the Wild SAP activities were not part of the original course activities but were a modification made during the first few weeks of the course to adapt to new circumstances. The Explorations in Human-Centered Design course was designed for an in-person studio pedagogy and was taught nine times in an in-person format in the department’s design studio space. Due to the COVID-19 pandemic, this course was shifted to a remote format during 2020 and 2021. Additionally, this was the first time I had been involved in the course, and I was inheriting a curriculum designed by two instructors and taught and modified by others over three years.

One design challenge that came with inheriting the course was that it was not always clear what the rationale was for certain course activities or structure decisions. At the beginning of the course, it was not clear to me what the role of the fifty-minute lecture was, and it became an opportunity for change. The course was taught in a flipped-classroom-like format. Students were exposed to

content through “studio prep” assignments with preparatory readings and videos. Concepts were then reviewed and practiced in the two-hour studio section. Following the studio, students completed a design-oriented assignment as homework. The weekly fifty-minute “lecture” meeting included students from all three studio sections but was historically not used for introducing new content to students prior to their assignment. In prior iterations of the course, the “lecture” meeting was often, but not consistently, used for guest lectures. Guest lectures brought in outside design work as a chance to see course concepts applied in work beyond the students’ design sprints, but I struggled to schedule guest presenters for every lecture.

The peer review component was another feature of the course that presented an opportunity for re-design. In the prior teaching of this course, ten percent of each student’s final grade came from several peer feedback and reflection assignments. Students were given time during the studio meeting to practice giving and receiving critique. Students then submitted a brief response sharing who they exchanged feedback with and the most important feedback they gave and received. During the first few weeks of the course, we found it difficult to find time for peer review during the studio, as many planned activities took longer to coordinate in an online environment. Students were spread across many time zones, making coordinating peer review outside synchronous classes difficult. The lecture component was unfortunately not positioned to provide time for peer review because the assignment due dates were staggered based on studio times. This meant that not all students had finished and submitted their assignments by the lecture, making it challenging to engage all students in peer review.

I created opportunities for students to share feedback each week. During the first few weeks, we received feedback that students enjoyed informally meeting their colleagues through breakout room activities. The digital format likely limited informal peer contact often present in an in-person lecture. Providing time for students to get to know their peers outside of the studio section became another design goal.

These parameters opened up an opportunity

to consider integrating an SAP learning activity that could take place in lecture, help students get to know their peers, support critique-like skills and replace the assignments in the rubric, expose students to design work outside of their assignments, and not depend on all student's having completed their design assignments. This led to the core structure in these seven Design in the Wild SAP activities of students finding examples of design in their everyday lives that they wanted to critique using principles learned in the course.

A few additional parameters influenced how the SAP activity was conducted in the lecture meeting. One of the challenges of creating an SAP in a remote format was finding ways to do group work without being co-located. Many prior SAPs included physical representations of examples and physical interaction during co-located group work. Access and ease of use of different technological tools shaped the SAP design in this case. Through the university, students had free access to Google Cloud tools such as shared drives, slide decks, and documents. While digital whiteboard technology was tried out at the beginning of the course, access problems forced a shift to a slide deck format. Zoom had been established as the digital meeting platform for the course. The breakout-room feature and random group assignment tools were also structurally significant in implementing the SAP.

A challenge faced in past SAP activities was how time-consuming and difficult it was to self-document the design process while doing design. So, another guiding constraint for this SAP activity was to make capturing and selecting design examples quick and easy.

Context

The Design in the Wild Interaction Design SAP activity occurred in the Explorations in Human-Centered Design course taught in the autumn of 2020 (EHCD_1). Seventy-five undergraduate students were enrolled in this course. Fifty-five students participated in the lecture activity.

The second unit in the EHCD_1 course focused on interaction design. This unit's deliverables were

described at the end of the weekly lecture. Then, students were introduced to related concepts and software through studio pre-work, practiced concepts in the studio meeting, worked on their sprint after the studio meeting, and submitted documentation in the course management system before the next week's studio. Studio prep included two short videos about interaction design and two short articles. One article covered the concepts of Don Norman's interaction design principles, and another covered navigation elements. Studio also reiterated concepts such as prototyping, high-fidelity and low-fidelity prototypes, wireframes, and navigation elements.

Student Design Work

In the Interaction Design Unit, students engaged in a one-week "design sprint" where they were required to individually create and pitch a prototype for a citizen science mobile application (app). Each student selected an intended user and an animal population to focus on. Students were required to create interactions that would support users in collecting text, numeric, and photo data types and create a feature to motivate users to participate in data collection. Marvel rapid prototyping software (<https://marvelapp.com/>) was used to create interactive prototypes with at least five hand-drawn screens. Finally, students submitted their work in the form of a ninety-second narrated video pitch showing a demo of the application prototype.

For example, one student created the "Alaskan Seabird Dyeoff" app to support tracking of decreasing Alaskan bird populations. The target user group was people living near or visiting the Alaskan coast. The app had several features, including a gallery to learn about birds, the ability to make and view bird reports, and the ability to view stats collected in different regions from app users. Figure 5_8a shows the three hand-drawn screens prototyped as an iPad app to support users in reporting bird data. From the main menu, if a user selects the camera, they are taken to the photo screen to take a picture, import a picture, or return to the previous page. After a picture is taken or uploaded, the user is taken to a reporting page where they can enter data such as the location, species, date, time, and contact information before submitting the report. This student implemented a badging system to

encourage users to collect data. Figure 5_8b shows a screenshot from the Marvel user flow viewer. This shows how the different screens are linked together through interactions. Finally, Figure 5_8c shows a screenshot of the YouTube video the student created to pitch her app. You can see the student clicking a button on the first page to demo logging into the app.

This assignment was created by the two faculty members who designed this course and was not significantly modified from previous versions of the course.

The Seeing Across Projects Activity

While the Design in the Wild Interaction Design SAP Activity represents a unique instance, it can be described using the SAP Activity model. The following section describes the overall sequence of the SAP elements, followed by a description of how this particular SAP captured design work, represented examples, used design examples, and applied learning to future design work.

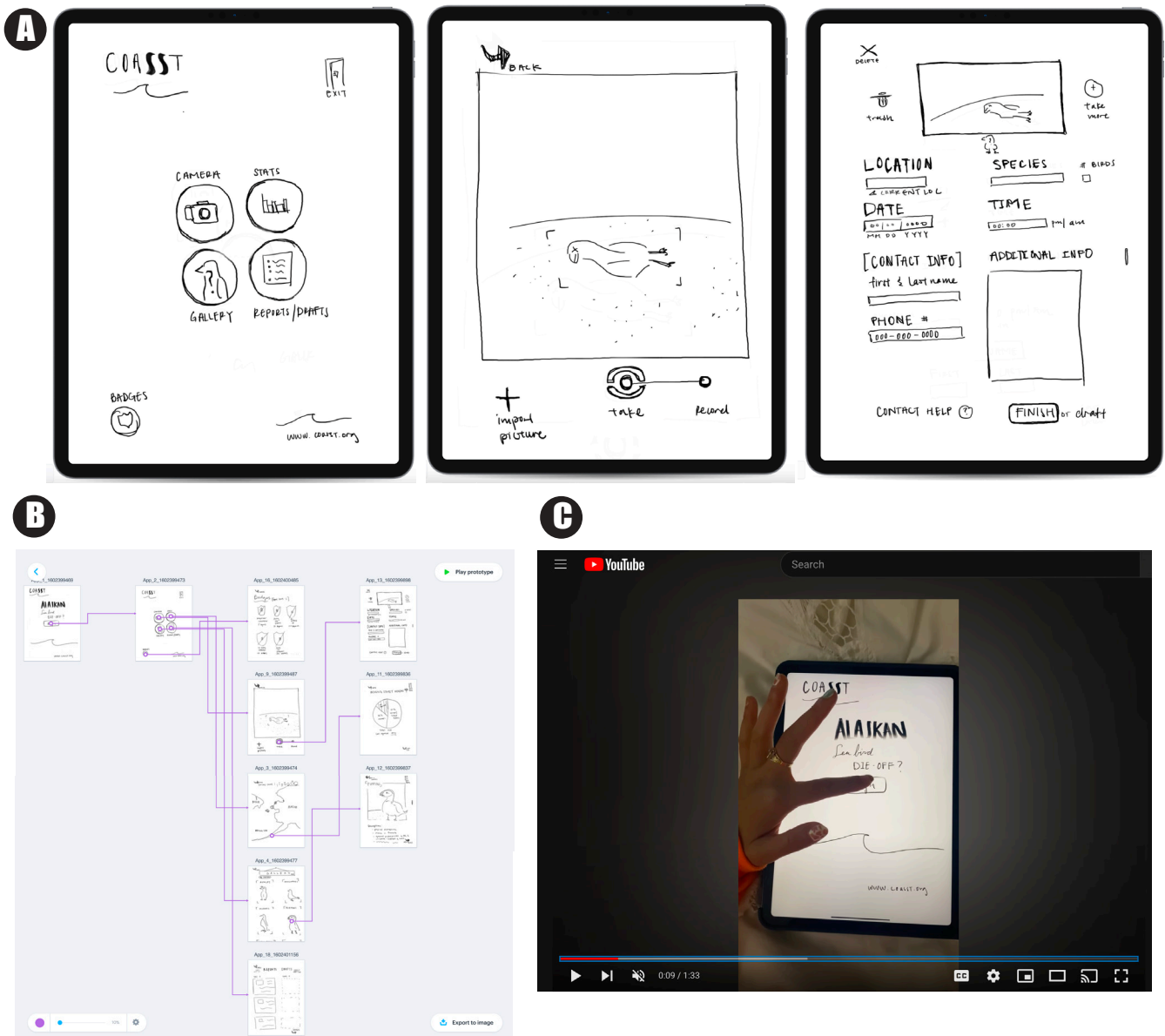


Figure 5_8: This figure depicts one student's design project, the "Alaskan Seabird Die-off App" low-fidelity prototype. Item (A) depicts three of the 10 "hand-drawn" screens used in the interaction design prototype. From left to right are the main menu, photo data entry page, and photo details page. Item (B) shows the interaction flow between screens pictured in the Marvel app used for prototyping. Finally, item (C) shows a frame from the YouTube video submission of the minute-and-a-half app pitch.

Sequence

In contrast to the Design Process Data Visualization SAP activity implemented throughout the ten-week quarter, the Design in the Wild Interaction Design SAP activity occurred during the first twenty minutes of one of the weekly fifty-minute “lecture” meetings. This meeting took place remotely in Zoom and included students from all three studio sections, the instructor (myself), a graduate student teaching assistant, and one of the three graders.

Before the meeting, the instructor (myself) created a digital slide deck with templates, instructions, and four examples. This was introduced to the teaching team in a weekly meeting, and the teaching assistant added an additional example.

During this meeting, the instructor (myself) introduced the activity and the learning objective of the activity to the students. Students were split into breakout rooms using the breakout feature in Zoom to split participants into rooms of equal size randomly. In this activity, there were fifteen groups. Most groups included four students, but a few were smaller. Students were to use and edit a shared Google slide deck. They were given five minutes to pick roles (scribe, facilitator, timer), document their names on a group slide, and introduce themselves to each other. Next, students were given four minutes to individually select and represent design examples on a slide using a template. Students could choose one of the five examples to save time instead of selecting their own. Each student then shared their example, and the group discussed similarities and differences across the group’s examples. The scribe was to document highlights from the discussion on the group’s slide.

Source and Capture of Design Work

In this SAP, the source of the design work was external to the students’ design sprint. Instead, examples of design selected from students’ daily lives were chosen. One reason for this choice was because of the staggered due dates of assignments for students in each studio section. At the time of the lecture, not all students had submitted their design assignments.

While the Design Process Data Visualization SAP

focused on the design process, the focus of the design capture in this SAP activity was the final product of someone’s design work. Students were asked to find an example of design in the real world that they wanted to critique using principles learned in the course. It was suggested that students use photos they might have already taken, take screenshots of technology, or use photos or screenshots publicly available online. So, in this case, the design capture was done through photos or screenshots. In some cases, students did the capture, and in other cases, students used traces of design products that were captured by others outside of the course and shared online. The rationale for these choices was to reduce the time and effort burden of students documenting design work.

Selection and Representation of Design Examples

Students were given three minutes to individually “generate examples.” This included selecting an example and representing it on a slide in a Google slide deck. Students were instructed to find an example of design in the real world that they were interested in critiquing using Don Norman’s Interaction Design Principles (visibility, feedback, affordance, mapping, constraints, and consistency)[2]. No specific constraints were given on how to identify and select designs. For this week, students were also allowed to use one of the examples the instructors had created to save time. In all other instances of DIW, students completed this step before the lecture to allow for more discussion time during the synchronous meeting.

Each individual example was represented on a slide in a digital slide deck. Students were each given a template slide to edit. A screenshot of the template slide is pictured in Figure 5_9. The slides were to contain a large image representing the design from the “real world” that students had chosen. In addition to the photo representing the design of interest, students were instructed to add comments in the speaker notes of the slide. This included information about where students found the screenshot or photo, an explanation of the design, and a rationale for why the student chose this particular example. Students were also asked to note who they thought the intended user of the

design was. Finally, students were to apply three of the six interaction design principles learned in this unit to the design. These could demonstrate something they thought the “design does well or an area of improvement.” Some slides from this activity did not include completed comments.

An example slide from Group 1 can be seen in Figure 5_10. Here, a student selected the architectural design of a stairway and door to examine. You can see a photo of the doorway in the top part of the slide. The student’s text

annotations can be seen in the bottom third of the image. They describe the intended user as “people who go up the stairs or need to go into the room.” They chose the interaction design principles of “mapping,” “consistency,” and “visibility” to describe how this example exhibits both some user-friendly and not-so-user-friendly interaction design features.

The collection of design examples was represented by each student’s slide being created in a Google slide deck. This deck included instructions, notes, and examples. The whole

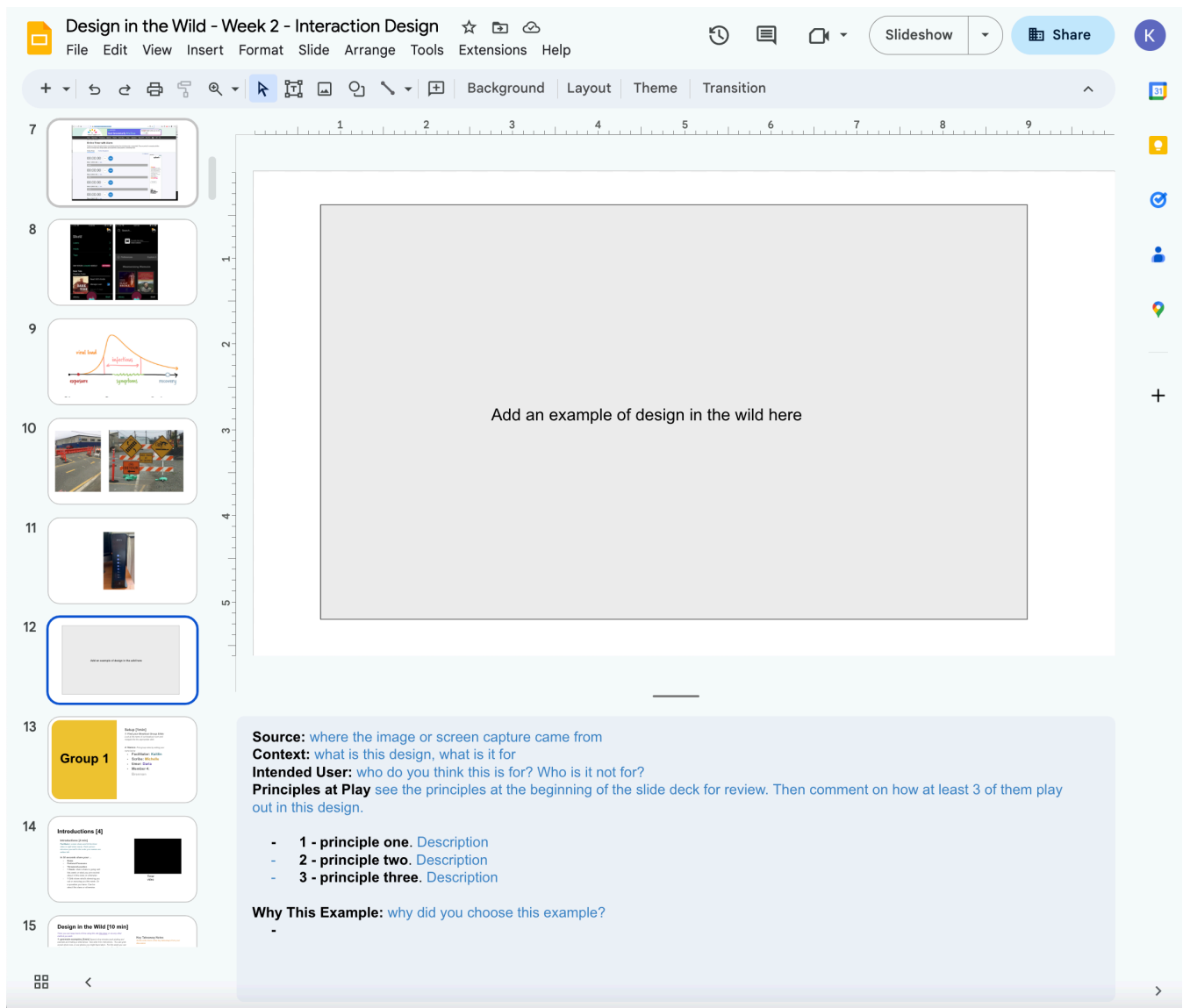


Figure 5_9: This figure shows the template students were given as a guide for representing and annotating their chosen design examples. The template was part of a slide deck that included instructions, examples, and the template pictured here. In the middle of the slide there is a large rectangle with text indicating that students should fill the slide with a visual of the design example they had chosen. In the speaker note section at the bottom of the slide, was an outline for students to fill in with additional information. This included the source of the example, a description of the design, the intended user, the rationale for choosing this example, and a description of three interaction design principles and how they are enacted in this design.

deck includes all instances. Each breakout group was given a section in the deck where they could group their slides. A tiled view of all slides in the deck can be seen in Figure 5_11.

Use of Design Examples

After the students had individually “generated examples,” they compared their examples. Recall that there were fifteen groups of about four students. The use of examples to support learning was carried out in two parts titled “share” and “discussion.” Instructions were written on a slide in each group’s section of the slides. This

slide can be seen in Figure 5_12. This slide also included notes for different roles (timer, facilitator, and scribe) and a section for the scribe to include notes and takeaways.

First, each student was instructed to share their slide, including what design they chose, why they chose this design, who they thought the intended user was, and what principles of interaction design they used to critique the design.

Next, students were instructed to spend a few minutes discussing what they noticed by

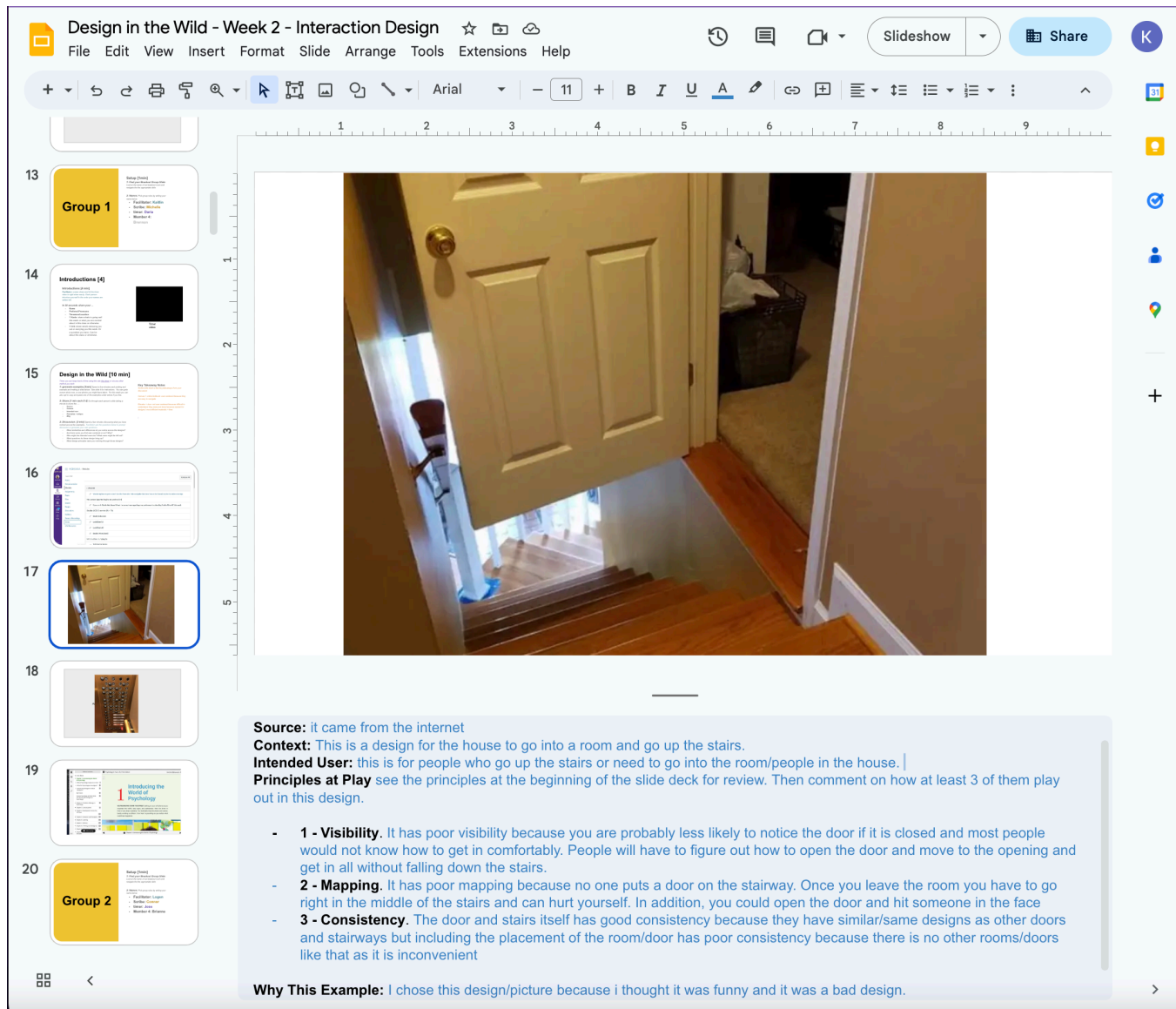


Figure 5_10: This figure shows the representation of one student’s design example using the template shown in Figure 5_9. Here, the student selected the architectural design of a stairway and door to examine. A photo of the doorway can be seen in the center of the slide. In the bottom third of the image, you can see the student’s text annotations. They describe the intended user as “people who go up the stairs or need to go into the room”. They chose the interaction design principles of “mapping”, “consistency” and “visibility” to describe how this example exhibits both some user-friendly and not-so-user-friendly interaction design features.

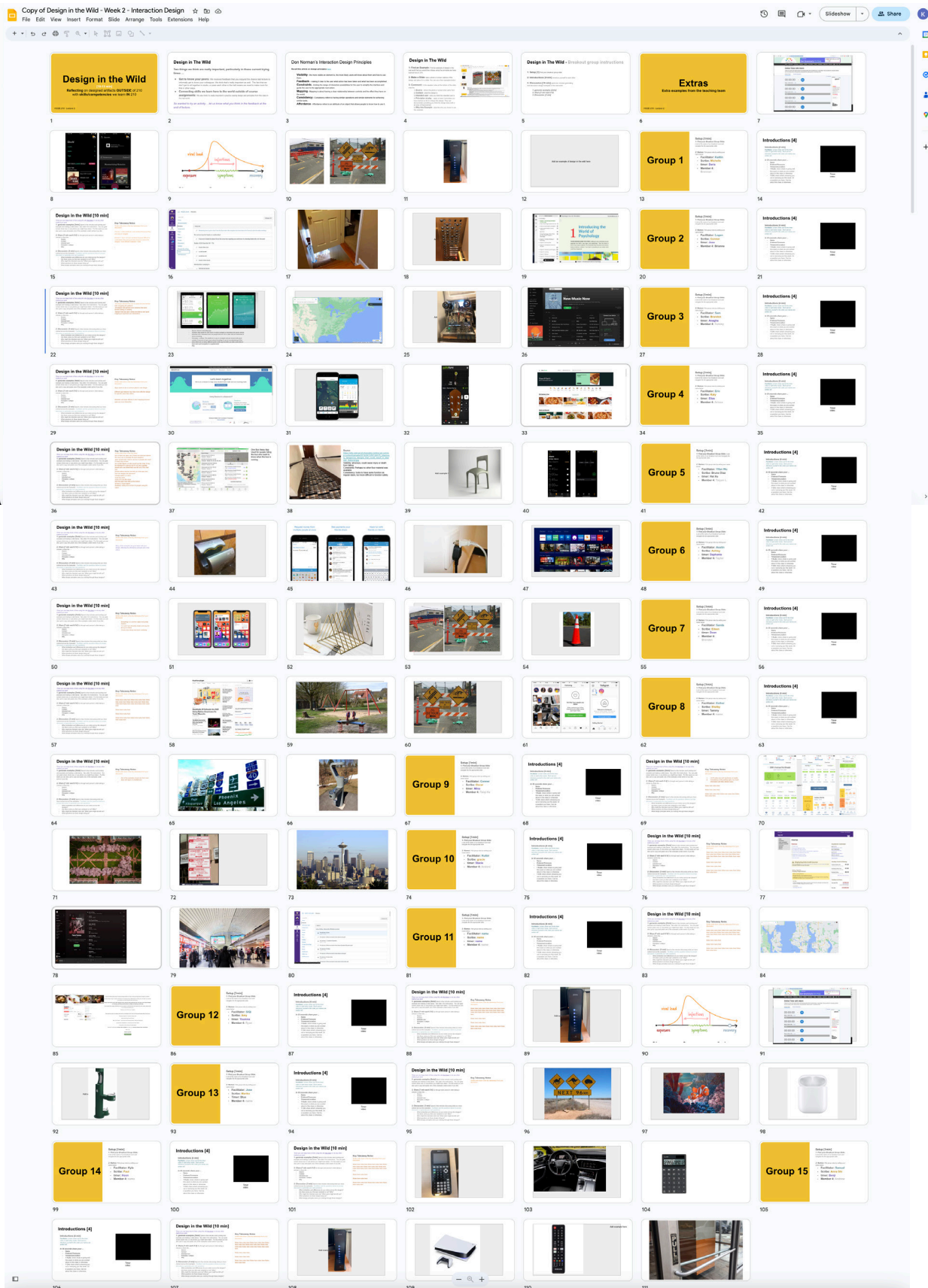


Figure 5_11: This figure depicts the collection of design examples represented by each student. The examples were aggregated together as part of one digital slide deck. The deck included templates, instructions, places for notes as well as the design examples.

Design in the Wild [10 min]

Timer you can keep track of time using this site [this timer](#) or via any other method you wish

1: generate examples [3min] Spend a few minutes each picking an example and making a slide below. See slide 4 for instructions. You can grab screen shots now, or use photos you might have taken. For this week you can also opt to copy and paste one of the examples under extras if you like.

2: Share [1 min each X 4] Go through each person's slide taking a minute to share the ...

- Source
- Context
- Intended user
- Principles / critique
- Why

2: Discussion: [3 min] Spend a few minutes discussing what you have noticed across the examples. Facilitator ask the questions below to prompt discussion or generate your own questions.

- What similarities and differences do you notice across the designs?
- Are there some you find user centered or not? Why?
- Who might the intended users be? What users might be left out?
- What questions do these design bring up?
- What design principles were you noticing through these designs?

Key Takeaway Notes

Scribe write down a few key takeaways from your discussion

Canvas + online textbook: user centered because they are easy to navigate

Elevator + door: not user centered because difficult to understand, they were just done because easiest for designs / most efficient materials + time

Figure 5_12: This figure shows the instruction and key takeaways slide one group filled out during the ‘use’ phase of the ‘seeing across projects’ activity. The slide was part of the same deck seen in Figure 5_11. The colored text was used to indicate jobs for the ‘timer’, ‘facilitator’, and ‘scribe’ in the group. The left side of the slide contained instructions, while the right side provided room for the scribe to fill in key takeaways from the groups’ discussion.

comparing the examples shared in the group. A list of questions was provided to help the facilitator guide the discussion. These questions included “What similarities and differences do you notice across the designs?”, “Are there some you find user-centered or not? Why?”, “Who might the intended user be?”, “What users might be left out?”, “What questions do these designs bring up?” and “What design principles were you noticing through these designs?”

In all other SAP activities, time was taken after the group work to share insights from each of the groups. Because of time constraints, this part of the activity was not included in the Interaction Design SAP.

Application of Learning to Future Design Work

The lecture meeting occurred after many students had submitted their interaction design assignment. However, due to the timing of the lab later in the week, one lab section (section C) had not. So, while there was no explicit effort to tie the learning from this activity to the current sprint, the students had the opportunity to do so because of the timing of the SAP activity.

There was no explicit support built into the SAP activity to help students tie their understanding of interaction design principles into any other design sprints in the course, as these covered different topics. However, the hope was that the repeated DIW activities over the course of the quarter would hone students’ ability to recognize and bring course principles into their everyday lives.

Citations

[1] Atman, C., Ahmer, A., Shroyer, K. and Turns, J. 2016. “Spend another day in our class talking about this research please”: Student insights from a research-based design thinking exercise. *Proceedings of DRS 2016, Design Research Society 50th Anniversary Conference* (Brighton, UK, 27–30 June 2016., 2016).

[2] Norman, D. 2013. *The design of everyday things*. Basic Books.

Chapter 6: Three Properties

The results of the depth-focused annotated portfolio were eight key properties of ‘seeing across projects’ (SAP) activities with implications on the feasibility or learning potential of activities. The eight properties are listed below.

1. **Design content:** The kind of examples in the collection.
2. **Sequence:** When the collection was used in relation to the design engagement.
3. **Source:** Where the examples came from.
4. **Capture:** The method used to document design work.
5. **Selection:** How examples were chosen for the collection.
6. **Representation:** How individual examples were represented in the collection.
7. **Aggregation:** How the collection was brought together and represented.
8. **Breadth of learning aims:** The scale of the ‘object of learning.’

Three of these properties were chosen for further analysis in this work: **content**, the kind of examples in the collection; **source**, where the examples came from; and **selection**, how examples were chosen to be represented in the collection.

This chapter briefly describes the seven SAP activities from the depth-focused annotated portfolio analysis. Then, the three properties are defined, followed by a description of that property in each of the seven SAP activities. Finally, the potential implications of that property on learning and feasibility are discussed.

7 ‘Seeing Across Projects’ Activities

Seven SAP activities were selected for the depth-focused annotated portfolio analysis: the Nameplate Use, Possible Project Deck, Project Update Discussion, Process Diagram and Rich Picture, Design Process Data Visualization, Design in the Wild - Interaction Design, and Process Diagram Board SAP activities. Each is described briefly below. A full description of the Design Process Data Visualization SAP activity and the Design in the Wild SAP activity can be found in Chapter 5.

Nameplate Use

During the third iteration of Making and Mapping (M&M_3a), twenty-one students and the two instructors (myself and another graduate student) created multiple iterations of a nameplate for use in the weekly meeting. The initial version of the nameplate was made from folded paper during the first meeting. The second version was made from laser-cut wood using a tabbed joinery technique. The instructor (myself) created a tutorial for students to follow. However, students were encouraged to modify the design and create multiple iterations if needed.

The main aim of the nameplate project was to introduce students to the laser cutter and give them a chance to use the tool. Two activities drew examples from this nameplate project. The Nameplate Use SAP activity aimed to help students notice design decisions and tradeoffs between the two fabrication techniques or between their work and the work of others in the

seminar. In this activity, examples focused on the students' design product, the paper or laser-cut nameplates.

This activity leveraged the design work of all course participants (students and instructors) by asking them to bring and use the most current version of their nameplates in the weekly meeting. This activity did not require additional documentation. The individual examples were represented by the physical nameplates brought to the meeting. The collection was represented by using the nameplates around the conference table. There was no formally structured activity to support students in seeing across the collection of examples other than using the nameplates in meeting discussions.

This SAP activity was carried out throughout the ten-week quarter. The nameplates were constructed during the first five weeks of the quarter and used as examples during each weekly meeting.

Possible Projects Deck

During the third iteration of Making and Mapping (M&M_3a), twenty-one students and the two instructors individually worked in the campus maker space. During the last four weeks of the quarter following the nameplate project, participants independently continued learning to use the laser cutter.

An SAP activity was implemented during this unit to support students in understanding the possibilities and constraints of fabrication using a laser cutter. The intent was to surface properties of what kinds of things could be made using a laser cutter to support students in choosing a project to spend ten weeks working on. This SAP activity focused on examples of "things one could make or do with a laser cutter."

During the last four weeks of the quarter, participants in the seminar searched for and selected two examples each week using whatever method they wanted. Participants represented each example with a slide in a digital slide deck. The slides featured a large photo of the example and text annotations, including what material was used, why this project was chosen, and two dimensions of interest to consider when

selecting a project. The collection was printed and represented as individual papers that could be stacked, moved, or arranged. During week seven and week nine, students used the examples in their weekly meetings. Students worked in groups of five to six to organize materials, assign roles (moderator, timer, note taker), choose a question to explore, explore that question with the examples, and prepare documentation. The group work was followed by a twenty-minute share back between the two groups.

The sequencing of this SAP activity occurred before students chose a project to spend the next ten weeks working on. Learnings from this activity were intended to help drive that decision.

Project Update Discussion

During the third iteration of Making and Mapping (M&M_3b), twelve students and one instructor (myself) individually worked in the campus maker space. Participants were tasked with individually completing three iterations of a personal project over ten weeks using laser cutting as the primary fabrication process.

Several SAP activities were implemented using these personal projects as the source of design examples. The Project Update Discussion activity, the Process Diagram and Rich Picture activity, and the Design Process Data Visualization activity all used aspects of these same projects to support students in learning by seeing across examples. The Project Update Discussion activity was designed to support students in completing their project work by providing a forum for getting feedback by discussing current work with their peers.

Students met in groups of four each week with the instructor (myself). Each ninety-minute meeting began with a set of reflection questions. Students individually responded in their digital notebooks. One of these reflection prompts asked students to consider their design work in the last week, what they wanted support on, and their plan for the next week. Forty minutes were dedicated to an open discussion at the end of each meeting. Each student was given nine minutes to share. In this SAP activity, the capture of design activity was the reflection prompt or from memory, though students could use artifacts or diagrams if they

wished. Examples were externalized verbally, and notes were captured in a shared digital document. Students were given roles of interviewer, note taker, timer, and interviewee to help facilitate the conversation.

This SAP activity took place throughout students' design work to support their projects by surfacing issues where they could compare their work to that of others in their group.

Process Diagram and Rich Picture

The Process Diagram and Rich Picture SAP occurred during the third iteration of Making and Mapping (M&M_3b) and focused on the same ten weeks of student design work. The aim of this SAP activity was twofold. First, it aimed to engage students in understanding and comparing their design process, as in previous activities. A secondary objective was to help students understand the role of the different kinds of visualizations in representing their design process. This SAP activity occurred during the first four weeks of the quarter and looked at examples of students' design activities in the past week.

In this SAP activity, students represented their process in two ways: A flow chart-like process diagram using Post-it notes and a "rich picture" [3]. In the process diagram representation, students were asked to think of four to six 'major activities' they had done in the past week. These 'major activities' were each written on a Post-it note, and the notes were arranged on paper to represent relationships between the activities. In the "Rich Picture" representation, students were asked to "create a rich picture of the past two weeks" of project work. Rich pictures are a diagrammatic form used to better understand a problem or system through visual depictions and iconography. Students were given a document explaining rich pictures and providing several examples. After creating both representations, students worked in pairs to silently offer feedback and discuss what they noticed. The whole activity took ten to twenty minutes.

Design Process Data Visualization

The Design Process Data Visualization SAP occurred during the third iteration of Making and Mapping (M&M_3b) and focused on the same ten

weeks of student design work. This SAP activity aimed to help students notice patterns in their design process. In this SAP activity, events and sub-events in the students' design process were the examples featured in the collection. This SAP activity is described in detail in Chapter 5.

The twelve students and one instructor (myself) engaged in design work throughout the ten-week quarter. While doing their design work, participants documented their activities in a personal digital journal and logged that same design activity in a collective database. The weekly seminar was used to develop and apply qualitative codes to the logged data and use visualizations of that data to compare design processes. During the first four weeks, students practiced developing and applying qualitative codes. Then, during the next five weeks, students iteratively developed and applied qualitative codes to their design work. One instructor (another graduate student with experience in data visualization) visualized the student's log data in an interactive dashboard. During the last four weeks of the course, the meeting was used to refine codes, code new data, and explore the visualizations of the design process.

Design In the Wild - Interaction Design

During the first iteration of the Explorations in Human-Centered Design (EHCD_1) course, around 75 students completed a short design assignment related to interaction design. Each student created and pitched a prototype for a citizen science mobile application (app). This SAP Activity is described in detail in Chapter 5.

In this iteration of the EHCD course, a recurring peer review assignment was replaced by SAP activities focusing on finding and assessing familiar examples of design using principles from the course. The first iteration of this activity was done during the interaction design unit. Examples were design products or systems from students' everyday lives.

The Design in the Wild SAP Activity occurred during the first twenty minutes of the 50-minute meeting. Before the meeting, the instructor (myself) created a digital slide deck with templates, instructions, and examples. Students worked in groups of three to four during the

meeting in digital break-out rooms. First, the groups were given time to introduce themselves and pick roles (scribe, facilitator, and time). Next, each student chose a “design in the real world” to critique using Don Norman’s interaction design principles [6]. These designs were represented as a photo or screenshot on a slide in the shared digital slide deck. Each student also annotated their slide with an assessment of how at least three interaction design principles were applied in this design. Students then shared their examples and discussed similarities and differences across the examples in their group. The scribe was to document highlights from the discussion in the shared slide deck.

Process Model Board

During the second iteration of Explorations in Human-Centered Design (EHCD_2), about 75 students engaged in an introductory design workshop. This two-hour workshop introduced students to user-centered design. Students worked in groups of three to four to re-design smart vehicle interfaces to better suit people’s needs. The activity was initially designed for an in-person format in prior course iterations, but I adapted it to be conducted remotely. The activity had five steps: introductions and team roles, defining the problem space, identifying the target user group and user needs, creating a user scenario and storyboard, and articulating interface design through a context sketch, interaction flow, and interface screen sketches.

In this iteration of the EHCD course, SAP activities were planned for the 50-minute remote meeting after each design deliverable was due. The Process Model Board SAP activity followed the introduction to the UCD workshop but drew examples from non-student work because many students joined the course during the first week and missed the workshop. This activity aimed to help students see design as a process and understand the key characteristics that make design different from other processes. Examples in this SAP activity were process models for both design and non-design processes. Design process models are visual representations of the steps in the design process and the expected relationship between those steps. There is not one but many commonly used design process models and representations of these models. Sixty-four

students participated in the activity.

The SAP activity took about 35 minutes. Before the remote meeting, the instructor (myself) set up a digital whiteboard with templates and instructions for each small group. During the meeting, a few slides were used to introduce the concept of design process models, and then students worked in breakout groups to compare three design process models and three non-design process models. Two design models were chosen by the instructor (myself). The other four were collectively selected in each group. A screenshot of the process model was used to represent each example. Each group’s collection was represented in a two-by-three grid of images with non-design models in the top row and design models on the bottom row. Students were instructed to look for similarities and differences between design and non-design process models and then within the design process models. Each group noted four dimensions of variance that they noticed when comparing the examples.

Content: What kinds of examples were in the collections?

Each SAP Activity used a collection of examples to engage students in comparison. However, different activities collected different kinds of examples. One property of the SAP activities was the **'design content'** represented in the collection of examples. However, content is a crosscutting feature. The content learners can compare is

determined by what is captured, what is selected and represented, and what is finally used from comparison by the students. This property is highlighted in the model in Figure 6_1.

Six different types of content were found across the seven SAP activities analyzed. This included the design **process, product, process models, performance, rationale, and experience**. Figure 6_2 provides a summary of the design content type used in each activity. The types of content represented in design collections were the focus of the analysis.

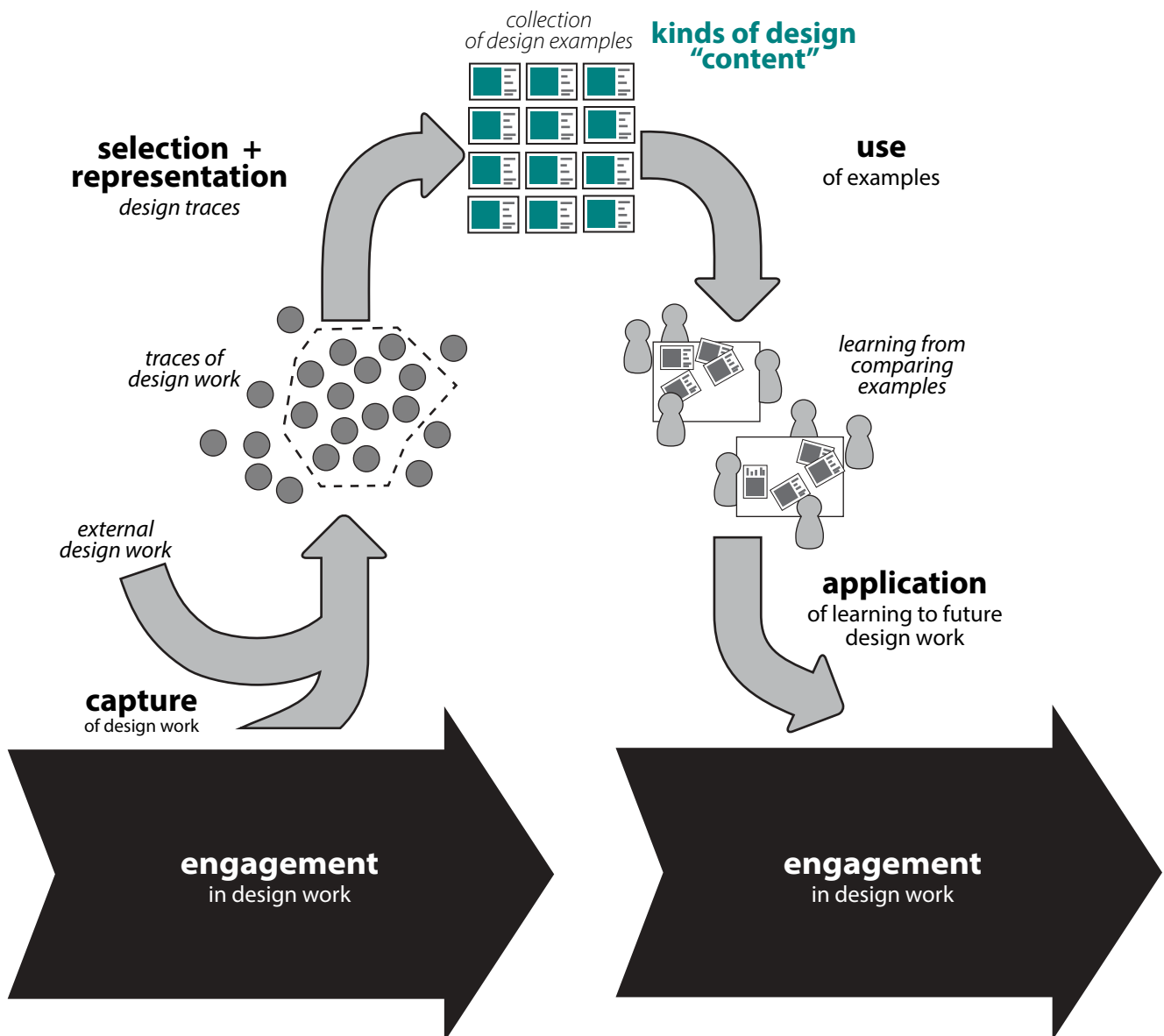


Figure 6_1: This figure depicts the six elements of the 'Seeing Across Projects' Activity Model: the engagement in design work, the capture of design work, the selection and representation of design traces, the use of examples, and application of learning to future design work. The feature of "design content" as represented in the design collection is highlighted in blue.

Content: Kind of Examples Represented in the Collection

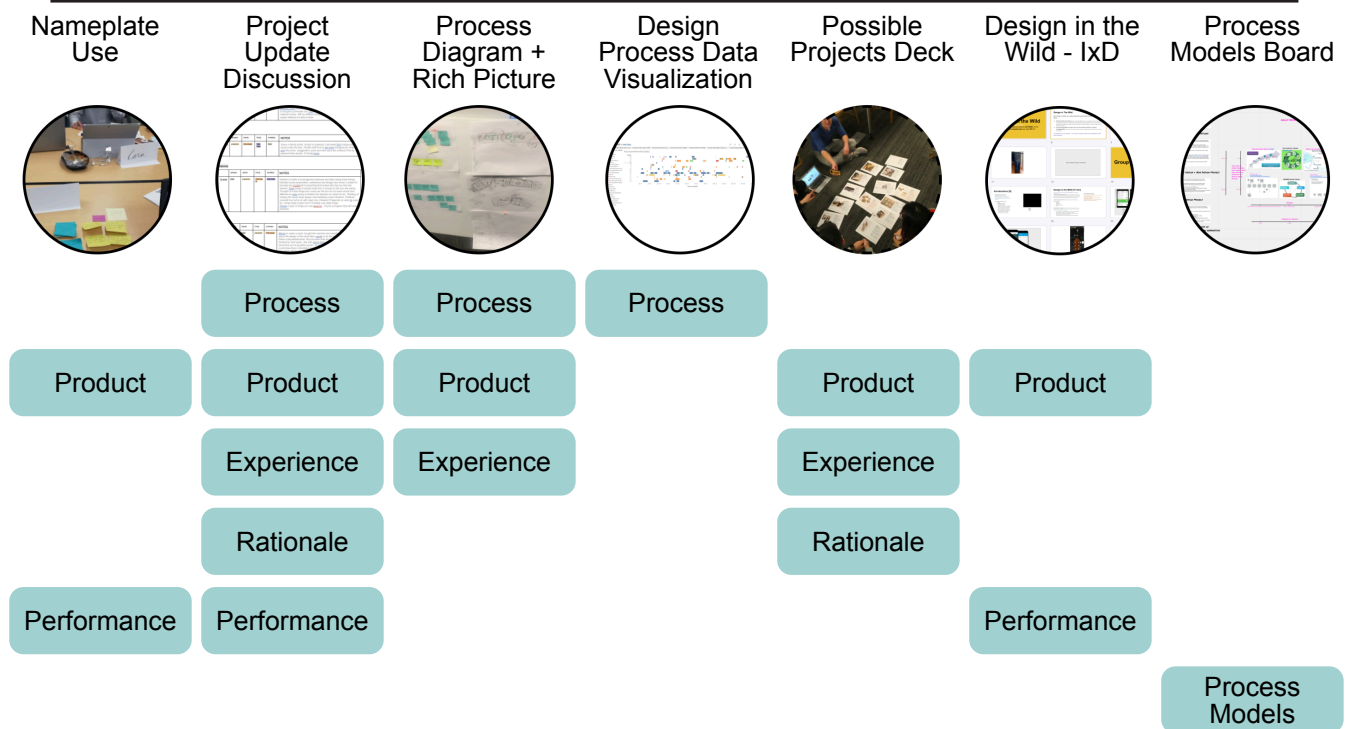


Figure 6_2: The figure above shows the different kinds of design content identified in each SAP activity. The seven SAP activities are labeled and depicted from left to right: Design Process Data Visualization, Process Diagram and Rich Picture, Project Update Discussion, Nameplate Use, Possible Projects Deck, Design in the Wild, and Process Models Board. The 6 kinds of design content (design process, product, experience, rationale, performance, and process models) are labeled below each SAP activity where they were present.

The following sections describe the six design content types seen across the SAP Activities and discuss some possible implications of content type for feasibility and learning.

Content in the 7 SAP Activities

Design Process

Three of the SAP Activities included examples of the design process. The **design process** refers to the activities carried out by the designers over time to create a design artifact. The process is an important topic in design learning because a good design process can lead to a good design product. All three activities took place in the Making and Mapping seminar, where students were tasked with individually working on three iterations of a personal project over ten weeks using primarily laser cutting as the fabrication process. In each of these SAP activities, students captured their design process at intervals throughout their project work.

In the **Design Process Data Visualization SAP Activity**, students individually documented their design process as they worked using design journals and then added log data from those entries to a collective database. Students and the instructor (myself) later developed qualitative codes to identify different design activities and qualitatively coded the log entries with these codes. The second instructor (another graduate student) represented that data through data visualizations in an interactive data dashboard. Design work was operationalized as “events” and “activities.”

For each activity, students also provided a start and end time, description, and the location of the activity. Events were defined as the largest grain size of log data. They might include something like “went to the maker space to buy materials and cut something on the laser cutter.” Activities were defined as sub-events and the grain size of interest for looking across. Examples of activities

for the prior event might include “walked over to the maker space, got out my material, edited my file, cut three sheets of wood, assembled my wood, took a picture, cleaning up material, and left maker space. Nearly 300 “activities” were captured by the twelve students during their project activity. Students also recorded where their design activity took place.

In the **Process Diagram & Rich Picture** SAP Activity, the student’s design process was also the content focus of the examples. In this activity, students represented their process in two ways: A flow chart-like process diagram using Post-it notes and a “rich picture.”[3] In the process diagram representation, students were asked to think about four to six “major activities” they had done in the past week. They were also asked to “arrange them on paper” to represent relationships between the activities. Due to the extensive time and effort required to log and code activity data in the Design Process Data Visualization, this SAP activity aimed to capture and represent the design process differently. In particular, time was represented as an ordinal rather than an interval data type. Additionally, instead of representing all activities, the design process was represented as a few “major activities.” Students mentioned activities such as searching for project inspiration, gathering information, sourcing and procuring materials, cutting and assembling, asking for help or using educational resources, modifications, problems or troubleshooting, sketching, and documenting or sharing projects.

In the “Rich Picture” representation, students were asked to “create a rich picture of the past two weeks” of project work. Rich pictures are a diagrammatic form used to better understand a problem or system through visual depictions and iconography. In the rich pictures and process diagrams, students captured steps and relationships between steps. The rich pictures captured parts of students’ design process as well as other design content (described later in this section). These representations were more varied than the Process Diagrams, but many students included pictorial representations of design activities or artifacts and arrows to represent relationships between them.

Finally, in the **Project Update Discussion** SAP Activity, groups of four students were each given nine minutes to share what they worked on in the past week, what they were struggling with or wanted support on, and what their plan was for the next week. This prompt was purposefully broad and did not specifically ask for the ‘design process’ or design process steps like prototyping, ideation, or problem scoping. However, each week, students shared descriptions of actions that, over time, described their design process. For example, students mentioned taking measurements, calculating dimensions, generating ideas, sketching, sourcing materials, fabricating, and troubleshooting. Students also described iterations. Sometimes, they used the term ‘iteration,’ but more often, they described ‘edits,’ ‘adjustments,’ or ‘modifications.’ The rationale for the broad prompt was that in past iterations of teaching the Making and Mapping seminar, it was difficult for students to define their work in terms of the abstract design process steps (e.g., project definition, ideation, or prototyping)

Design Product

The ‘**design product**’ was another type of design content used in the example collections. Five SAP activities included examples of design products. Design product refers to the artifact being designed. As the design process was proving difficult to capture, some SAP activities were designed considering what might be easier to capture than the design process. Because product traces are a natural byproduct of the design process, they were feasible to collect both from students’ design work and design work external to the learning environment. Two SAP Activities used examples of students’ design products, while the other two used public traces of design products created by others.

In the **Nameplate Use** SAP Activity, students’ wooden nameplates were used to represent the design artifact. Several characteristics of the design were represented by the final physical artifact, including the material used, aesthetics, structure, and size. Students brought their nameplates to the weekly meeting and used them on the table. Students created and used a paper version of the nameplate during the first meeting. Later in the quarter, students constructed a laser-cut nameplate to replace their paper version. The

paper and laser-cut versions were visible each week during design meetings.

In the **Possible Projects Deck** SAP Activity, students gathered examples of “things one could make or do with a laser cutter.” These examples represent design products in that they were images of design artifacts. Students were asked to find and represent a project using a photo and text annotations based on the product photo. These annotations included the material used, the rationale for choosing the project, and two interesting dimensions they noticed that could be used to select a project. Examples represented different kinds of artifacts, including clocks, key chains, phone stands, boxes, lanterns, jewelry, coasters, shadow boxes, board games, wall hooks, phone cases, and stands. Most of the artifacts were made of wood, cardboard, or acrylic. However, other materials such as stone, fabric, food, and metal were also included. Examples also demonstrated a range of fabrication techniques. For example, different techniques for 3D construction included stacking slices, interlocking slides, tabbed joinery, and living hinges.

In the **Design in the Wild** SAP Activity, students selected one instance of a “design in the real world” to critique with interaction design principles. Like the Possible Project Deck Activity, students chose a design product and then represented it on a digital slide using a photo or screenshot and several text annotations. Students chose a variety of examples that included both physical and digital artifacts. Digital artifacts included mobile and web applications for music or movie streaming, finance, map navigation, guitar tuning, alarms, food delivery, and public transportation tracking. Physical artifacts included products such as a calculator, coffee maker, hand dryer, headphone storage case, and more extensive architectural interphases like staircases, doors, playgrounds, or even the layout of the university’s quad.

In the **Process Diagram & Rich Picture** Activity, students were asked to create a “rich picture” of the past few weeks of project work. Students were not explicitly asked to include representations of the design product, but a few rich pictures included drawings of the artifacts they were making. For example, one student drew

sketches of two versions of her tea holder box and annotated what features were changed.

In the **Project Update Discussion** SAP Activity, students were asked broadly to share their work and get feedback. In addition to sharing their design process, students also shared examples of design products. Examples of design products were primarily shared through verbal descriptions of what students had or were planning to construct. However, they were asked to consider using visual aids (sketches, photos, or physical objects) in their discussion. Occasionally, students brought one or a few in-progress artifacts to the meeting to discuss and show to other students.

Both the Project Update Discussion and Process Diagram & Rich Picture activities included examples of in-process artifacts rather than just the final product.

Designer Experience

Another category of design content seen in the collections of examples is “designer experience.” This phrase is used to parallel the term “user experience” in user-centered design. Designer experience refers to what it was like or might be like for the students to engage in design work. The designer experience was not explicitly asked for in any SAP activities. However, when the examples of design work were left somewhat open-ended, students reported their emotions and expectations. Three SAP activities represented “designer experience” type content in the collection of examples.

In the **Project Update Discussion** SAP Activity, students included examples of process, product, rationale, performance, and experience. As part of sharing their project work, students talked about what it was like to do that project work. Students described characteristics of their experience doing design work, such as feeling accomplished, scared, unsure, frustrated, worried, finding things difficult, or being comfortable. They also talk about expectations, such as how long something should take.

In the **Possible Projects Deck SAP Activity**, students gathered examples of “things one could make with a laser cutter. For each example of a design product, students were asked to share

why they selected that example and two potential dimensions that might be worth considering about projects. As part of this documentation, some students included examples of what they thought the future experience of making these design products might be. For example, students mention anticipating that certain projects might be “fun,” “hard,” or “interesting” or might fill them with “pride.” One student also mentioned working alone or together as a dimension that might affect their experience.

Finally, the **Process Diagram & Rich Picture** SAP Activity also included examples of designer experience. While the Process Diagram was strictly focused on process, the rich picture left more room for students to share different kinds of examples related to their design work. A few students included representations of themselves in the rich pictures through character drawings or stick figures. Placing themselves in the design process can be seen as a representation of experience by considering their role in the design work. Additionally, in some of the rich pictures, the figures were given different expressions at different points in the process.

Design Rationale

Design rationale refers to the explicit articulation of decisions made during the design process and the reasons why those decisions were made [5]. It typically includes alternatives considered, trade-offs between alternatives, and the reasoning behind a certain design decision. Two of the seven SAP activities included design rationale. In some cases, students were asked for a rationale. In other cases, students shared their rationale for design choices when asked more generally to share design work.

In the **Possible Project Deck** SAP Activity, students gathered examples of “things one could make or do with a laser cutter. In addition to providing a representation of the design product, students were asked to share their reason for choosing this example and describe two dimensions they might consider when choosing projects. In these additional annotations, students were asked to choose a dimension they might consider when comparing or choosing a project. However, sometimes, students went beyond mentioning a dimension to describing why that

was a desirable criterion for project choice and how other parameters might affect that criterion.

The **difficulty** of a project was a consideration that came up in many students’ dimensions. Some students just mentioned difficulty level as a consideration. For example, one student wrote that it “seems like it [the project] would be pretty challenging for me.” Another student wrote, “This [project] seems pretty doable and not too hard.” In other examples, students considered how different features might contribute to the difficulty level. For example, one student relates geometric features to difficulty: “Considering the amount of holes and how to fit this, the difficulty of this project might be high for a beginner like me.” Students also related difficulty to their current skill set and availability of instructions. “Should be pretty easy, there are instructions provided.” Another student writes, “Difficulty: have to learn electrical components on top of the laser cutting.” Connections were also drawn to the features of the laser cutter and material. One student writes, “On the Mill [a campus makerspace] laser cutter, there are not settings for cutting cardboard so getting this effect might take a lot of trial and error.”

The **cost** was another consideration students mentioned frequently. In particular, many students considered how the availability, type, or amount of material might affect the cost of their project. For example, one student wrote, “This project could potentially be very pricey because of the amount of wood that it uses.” Another student wrote that “cardboard is free, and also very easily accessible.” One student described the link between cost and process, noting that “materials don’t seem expensive, but I think I would make a lot of mistakes, so [the cost] may be high.”

Students considered a number of other parameters, such as personalization, utility, time, and durability.

In the **Project Update Discussion** SAP Activity, students were given nine minutes to share what they worked on in the past week, what they were struggling with or wanted support on, and what their plan was for the next week. They were not explicitly asked to give a rationale for their choices, but students did talk about design decisions they made, alternatives they

considered, and reasoning for their final choice. Some common design decisions related to where to get materials, what materials to use, what kinds of projects to make, or what software to use for design file drafting.

In the Design in the Wild SAP activity, students were asked to provide a rationale for their choice of example, much like in the Project Possibilities Deck SAP activity. However, in this case, students' responses did not relate to the design decisions or tradeoffs of the design being considered or future design work.

Design Performance

Another type of design content used in the example collections was 'design performance.' Three SAP activities included design performance as part of the content in their collection of design examples. Design performance refers to the quality of the design and how well it meets its requirements. The word performance is drawn from the concept of design-performance space in computational making and parametric design [2].

In the **Name Plate Use** SAP activity, performance was included, but without much structure. Recall that in this SAP activity, students used the various iterations of the nameplate they had created in the weekly seminar meeting. The nameplates were used to support discussion facilitation, so while specific design criteria were not articulated prior to design, it was possible for students to notice variations in performance characteristics. For example, many of the paper nameplates did not stand up well. The construction of the laser-cut nameplates made them bulky and difficult to carry back and forth from the meeting. Some of the names were difficult to read when sitting across the room.

The **Design in the Wild** SAP activity intentionally included an assessment of the design artifact as part of the collection of examples. In this case, the designs being assessed were not physically present, but students used a photo to represent a design product they were familiar with in their everyday lives. In the example representation, students were asked to pick three of Don Norman's six interaction design principles (visibility, feedback, affordance, mapping, constraints, and consistency)[6] and use them to

assess the user-friendliness of different features of the designs.

Finally, the examples in the **Product Update Discussion** SAP Activity included content related to design performance. This SAP asked students to broadly report on what they had done in the last week, planned to do in the next week, and what they were struggling with or wanted feedback on. As part of the criteria for their design projects, they were asked to make at least three versions (iterations). As part of discussing their projects, students shared problems they had encountered with certain designs or things they wanted to change in future versions.

Design Process Models

One of the seven SAP Activities looked at the design process through examples of design process models rather than specific design work for a particular project. Design process models are visual representations of the steps in the design process and the expected relationship between those steps. There is not one but many commonly used design process models and representations of these models.

In the **Design Process Model Board** SAP Activity, the collection was made up of representations of both design and non-design process models. Two models were chosen by the instructor (myself), and each of the seventeen groups of students was asked to choose four more. Overall, twenty-three different non-design processes were represented in the collection. This included biological or ecological processes such as the carbon cycle, photosynthesis, mitosis, and the water cycle. Other processes included how a bill becomes a law, the recycling cycle, the writing process, and the business cycle. Of the thirty-five representations of the non-design process, only two shared the same representation. Twenty-eight unique design representations were included in the collection.

Insights on Feasibility and Learning

Considering the SAP activity model, activities are intended to support students' design learning through the comparison of "examples." This

involved engagement in design work, the capture of traces of that design work, selection and representation of examples, and the use of those examples in ways that could support learning by seeing across examples. The kind of content being captured, represented, and compared by students had an impact on what was made possible to learn and how feasible it was to conduct the SAP learning activity.

There are multiple kinds of design content to consider

One takeaway from looking across this body of work is that there are many different kinds of design-related content that can be captured, represented, and looked across. These Research Through Design inquiries began with a focus on capturing and looking across the design process. However, through encounters with unique constraints and inspiration in different SAP activities, additional content areas were uncovered.

Some SAP activities focused on very specific content (like the Design Process Data Visualization SAP), while others left content more open-ended (such as the Project Update Discussion). In the SAP activities analyzed, leaving content open allowed for the surfacing of additional areas of content to consider capturing. Design experience, for example, was not something initially considered of interest, but instead was the results of what students shared when asked to generally report on their experiences working on personal projects in the Making and Mapping seminar.

These results provide a starting point for considering what kinds of content can be captured to support learning by looking across projects. Each of these areas of content is quite broad, and future work is needed to better understand what kinds of content best support specific learning outcomes.

Feasibility: Some kinds of content are easier to capture than others

One of the driving factors for exploring different kinds of design content to capture, represent, and compare in various iterations of SAP activities was how difficult it was to capture and make

sense of the design process examples in the three iterations of the Making and Mapping seminar. Another insight that emerged from looking across the types of content used in the seven SAP activities was that some types of 'design content' were more feasible to capture than others.

One measure of the feasibility of capture was simply if it was an extra step. For some kinds of content, documentation was a natural byproduct of engagement in design. For other kinds of content, extra processes were required to capture these design elements. In the quote below, Lee and Lai describe how the design product leaves a trace of the final design decisions made but not the process, experience, or rationale for those design decisions.

"The primary goal of design is to give shape to an artifact - the product of design. This artifact is the result of a complex of activities - the design process. But the artifact is in a concrete form that does not (except in very subtle ways) manifest the process of creation. It does not give evidence for the motivations that initiated its design, the stated requirements, the conditions that gave rise to its shape, the struggles and deliberations and negotiations, the trials and reflections, the careful balancing and tradeoffs of various factors, the reasons for its particular features, the reasons against features it does not have, and so on. Such background information can be valuable, even critical, to various people who deal with the artifact..." [5]

Representations of design '**product**' were feasible to capture as examples because minimal additional documentation was needed. In the Nameplate Use SAP Activity, students did not carry out additional documentation to represent design examples; the artifact itself was the example. By bringing the artifact to meetings, it was possible to notice different materials, aesthetics, size, and geometry of the design product examples. However, students did not always remember to bring the nameplate to the weekly meeting. In the Design in the Wild Deck and Possible Project Deck SAP Activities, students did not document their own work but instead found examples of others' design work. This was made possible by the ease of finding photos or taking photos of the design products of others.

In the Process Model Board SAP Activity, **process models** were very feasible to collect because students were not generating process models but instead used representations of processes that someone else had created. So, while process model representations are not a natural byproduct of doing design work, they are a natural byproduct of teaching the design process. It was possible to have students easily find examples of process models because representations are prolific on the web, in articles, and in textbooks.

Rationale, experience, process, and performance were not naturally documented as a byproduct of design and required the students to spend extra time and effort capturing examples of these kinds of content. The documentation of the design process took more time and effort than the design rationale, experience, or performance in the particular SAP activities analyzed. However, some of this can likely be attributed to the method of documentation used and not solely the type of content being documented.

In the Design Process Data Visualization SAP, a significant amount of time and effort went into capturing and representing the student's design process as well as supporting students in learning methods of capture and representation. Significantly more time was spent on capture and representation than was able to be used on the comparison of process examples. The Process Diagram and Rich Picture SAP Activity used more feasible methods of capturing design in terms of time and effort but still required more time-consuming and frequent documentation than the capture of product content.

The rationale, experience, process, and performance content types were sometimes present in the documentation of others but not consistently. For example, in the Possible Project Deck SAP Activity, some examples of possible projects referenced tutorials or blog posts where the designer described their process, experience, and rationale. However, this documentation was not consistent or present in all examples.

While rationale, experience, process, and performance required additional documentation, product documentation was leveraged in some

SAP Activities to help students create traces of the other design content types. Some students documented their design activity in the Design Process Data Visualization SAP Activity through photo journaling. They took photos of what they were designing during their design work and used these representations to create written documentation of their process, experience, and rationale later. In the Design Update Meeting SAP Activity, students were encouraged to bring the artifacts they were making to help initiate questions and conversations about process, product, and rationale. In the Design in the Wild Deck SAP Activity, students used photos or screenshots of interaction design products to investigate performance by critiquing them through Don Norman's Interaction Design Principles. In the Nameplate Use SAP Activity, bringing the nameplate to weekly meetings for ten weeks provided a trace of iterations, a core concept in the design process.

While the design rationale and experience types of content were not documented as a natural byproduct of the design process, they were promisingly feasible to document. When students were given more freedom to include content of interest from their design work (for example, in the Project Update Discussion and Possible Project deck), they included experience and rationale even if it was not explicitly asked for. The unprompted inclusion of this kind of content suggests that it could be somewhat feasible to capture.

The analysis of types of content included in the example collections of the seven SAP Activities has shown that some types of content may be easier to capture than others. When time and effort are limited, deciding how much to dedicate to capture is important. Future work is needed to better understand the relationship between design content type, capture method, and feasibility.

Contrast: Examples of non-design content may be needed

Nearly all of the SAP activities exclusively selected examples of design work. It was natural to assume that in order to learn about design, we should compare different examples of design. However, when viewed through the lens of

Variation Theory, exclusively collecting examples of design work can hamper the ability to create patterns of 'contrast' for important objects of learning.

A core tenet of variation theory is that to comprehend what something is, it is necessary to compare it with examples of what it is not (see Chapter 2). 'Contrast' is the pattern of variance where 'defining critical features and aspects' are varied while all other features are kept invariant. The goal of this pattern is to allow the learner to 'separate' out specific aspects that define the object of learning from other aspects.

For example, to learn the concept of a triangle, the number of sides is a critical aspect (dimension). Having three sides is a 'critical feature' (value) that defines a triangle as different from other geometric shapes. A pattern of 'contrast' could be created by showing a square, an octagon, and a triangle and keeping aspects such as size, color, or orientation invariant. In this case, the number of sides (a critical aspect) is varied to show how three-sidedness is one 'critical feature' that makes a triangle different from a square. The dimension 'number of sides' can only be varied by having examples of triangles and other non-triangular shapes.

All SAP activities analyzed, except the Design Process Board, used examples of design content: design products, design process, design process models, design rationale, design performance, and the experience of doing design. This made it difficult to create patterns of contrast with the defining features of the design. Consider two SAP activities: the Design Process Model Board and the Design Process Data Visualization.

In the Design Process Board activity, three examples of non-design process models and three examples of design process models were compared. Having both design and non-design process models made it possible to create patterns of contrast between what makes the design process different from other kinds of processes. Having different design process models made it possible to generalize elements of the design process. For example, 'number of steps' is an aspect of all processes. Different design models and different non-design models

represent the same processes as having variable numbers of steps. Ideating, however, is a step that is unique to a design process. We can notice ideation through the comparison of processes that have and do not have ideation. This requires having examples of both design and non-design processes to compare.

In the Design Process Data Visualization activity, students identified periods of design activity and then coded those with design process codes. Students were asked to capture only design activity. So, while there were lots of examples of different design activities, there were no explicit examples of non-design activities to use as contrast. If the object of learning is understanding that design is a process and what makes the design process different from other processes, then it is not possible to open up certain critical aspects from examples in the Design Process Data Visualization. However, the presence of different design activities does support contrast that can open up critical aspects of different design activities. For example, 'defining aspects' of ideation, problem scoping, or modeling.

In this SAP activity, significant time and effort were needed to develop, learn, and apply the qualitative codes of activity type to students' descriptions of activity. It was found that many of the students could not easily identify design process steps in their own design work (e.g., defining the problem, modeling, and ideating). This suggests that the steps themselves would have been appropriate objects of learning for this SAP. In this case, the pattern of 'contrast' could be used to show critical features of how ideating and problem definition are different. Ideation is generative, but testing is not.

The kinds of examples needed to create patterns of 'contrast' depend on the 'object of learning' (learning objective). Therefore, examples of non-design content might not always be needed. However, in any case, where we want students to discern a defining aspect or feature of the design, examples of non-design content will be needed.

Source: What is the Origin of the Traces of Design Work?

Another property of the SAP Activities was the ‘**source**’ of design examples. “Source” refers to the origin of the traces of design work (see Figure 6_3). The traces were sourced either from the learning environment (**internal**) or outside the learning environment (**external**). In four SAP

activities, the source of traces was the students’ and instructors’ current design projects (internal). In the other three activities, the source of the design examples was external design work conducted and publicly documented by designers outside of the learning environment (external). Figure 6_4 provides a summary of the type of source used in each of the seven analyzed activities.

The following sections describe the two types of sources seen across the analysis of seven SAP Activities and discuss some possible implications of those sources for feasibility and learning.

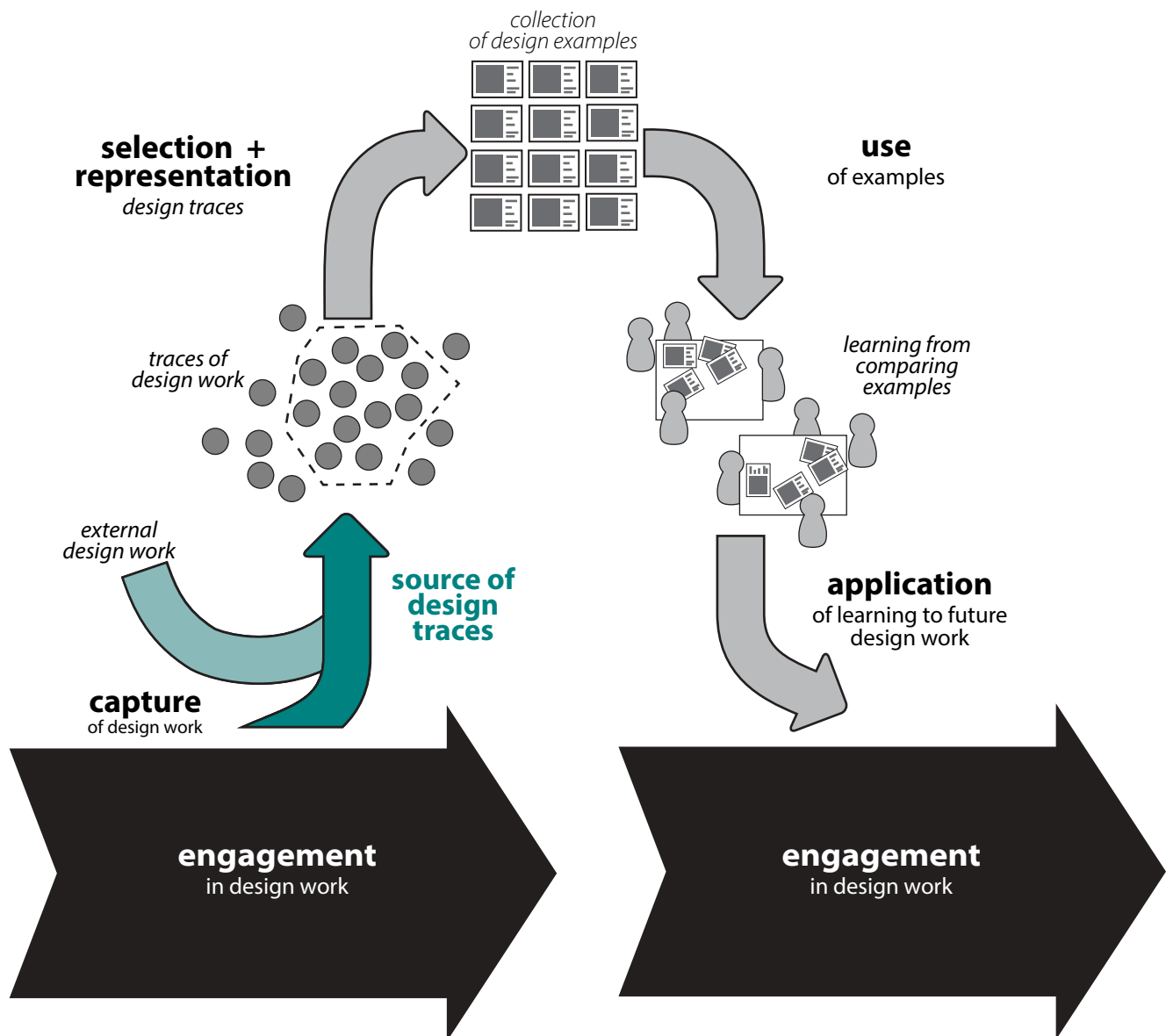


Figure 6_3: This figure depicts the six components of the Seeing Across Projects Based Learning Model: doing design work, capturing traces of design work, selecting and representing examples of design work, using collections of design representations, and applying learning to future design work. The capture element is highlighted.

Source: Origin of the Traces of Design Work

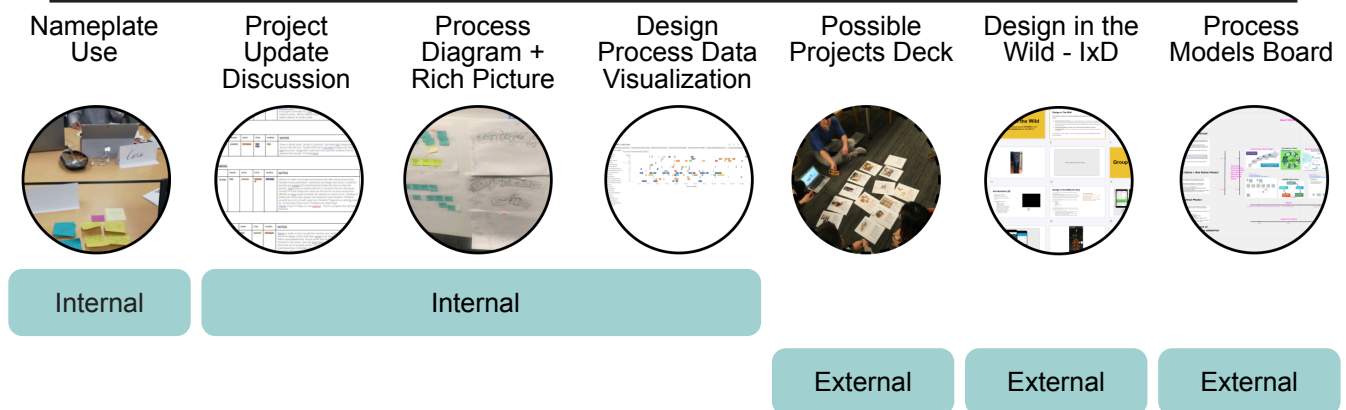


Figure 6_4: This figure summarizes the type of source used in each of the seven RtD Prototypes analyzed. Each prototype is depicted as a column containing the prototype's title, representative image, description of the source used, and the source type (internal or external). The Nameplate Use, Project Update Discussion, Process Diagram and Rich Picture, and Design Process Data Visualization prototypes all leveraged the current design projects of students and instructors as the source of design traces. These represent internal sources. The other three Prototypes (Possible Project Deck, Design in the Wild, and Design Process Model Board) leveraged publicly documented design examples external to the learning environment as the source of design traces.

Source in the 7 SAP Activities

Internal to the Learning Environment

Four SAP activities (the Nameplate Use, Project Update Discussion, Process Diagram and Rich Picture, and Design Process Data Visualization activities) leveraged the current design projects of students and instructors as the source of design traces.

During the first and second units of the third iteration of Making and Mapping (M&M 3a), the twenty-one students and the two instructors were tasked with creating multiple iterations of a nameplate for use in the weekly meeting. The design work that went into creating the nameplates was the source for the **Nameplate Use** SAP Activity.

Throughout the quarter, both students and the two instructors (myself and another graduate student) created at least two nameplates for use in the weekly meeting. The initial version was made out of folded paper during the first meeting. The second version was made from laser-cut wood using a tabbed joinery technique. The instructor (myself) created a tutorial for students to follow. However, students were also encouraged to modify the design and create multiple iterations if needed. The Nameplate Use SAP Activity leveraged the design work of all course

participants (students and instructors) by asking them to bring and use the most current version of their nameplate in the weekly meeting.

During the second quarter of the third iteration of Making and Mapping (M&M_3b), twelve students and one instructor were asked to create at least three iterations of a personal project that utilized laser cutting as the primary fabrication process. These projects were the source for traces for three SAP activities: **The Project Update Discussion, Process Diagram and Rich Picture, and Design Process Data Visualization Activities.**

Participants self-documented their work through journals, activity log entries, and written reflections. In the Project Update Discussion, students had nine minutes to discuss what they had done in the past week on their project, what they were struggling with, and what they planned to do next week. In the Process Diagram and Rich Picture Activity, students created diagrams and rich pictures of their project work and compared them in pairs each week. The instructor (myself) also participated and used her work as examples to help explain the diagramming task or to share in pairs when a student was absent. Finally, in the Design Process Data Visualization, all participants (both students and the instructor) logged their design work in the form of activities

with timestamps. These logs were coded and visualized for comparison.

In these 4 SAP activities, the examples represented and later compared to elicit learning outcomes were drawn from project-based design work done within the learning environment. Students were learning from comparing examples of their own design work with their peers and, in some cases, the instructor (myself).

External to the Learning Environment

The other three activities (Possible Project Deck, Design in the Wild, and Design Process Model Board) leveraged publicly documented design examples external to the learning environment as the source of design traces.

In the third unit of the third iteration of the Making and Mapping seminar (M&M_3a), students and one instructor were asked to represent examples of things that could be made with a laser cutter. These examples were used in the **Project Possibility Deck** Activity. Participants decided where to source the traces of design work for these examples. Some suggested sources included searching the internet, asking friends, and finding physical objects in the maker space. Participants were asked to provide links or descriptions of where they had found traces of design work. Participants used multiple external sources, including tutorials, blog posts, online retailers, and photos from Google image searches.

For the Interaction Design unit in the first iteration of the Explorations in Human Centered Design course (EHCD_1), students were asked to find examples of “design in the real world that they wanted to critique” using Don Norman’s Interaction Design Principles. These examples made up the **Design in the Wild** collection. A few teaching staff members also completed the assignment to provide representations the students could use. Participants decided where to source the traces of design work for these examples. Some suggested sources included finding screenshots or using photos they had taken. While participants were asked to cite the source of the traces they used, many students did not, making it difficult to determine what sources were used.

For the Introduction to User-Centered Design unit in the second iteration of the Explorations in Human-Centered Design course (EHCD_2), students were asked to find models of both design and non-design processes. These models made up the **Design Process Models Board** collection. Participants decided what sources to use. Some suggested sources included using a compendium of design models from the Dubberly Design Office [4], other classes, design blogs, or Google image searches. Participants were asked to cite where they had found the process models. Participants used multiple external sources. Many of the design models were sourced from the Dubberly Design Office’s compendium of design models. This compendium is a digital book of over one hundred descriptions of design and development processes from multiple design disciplines. Many other models were found in blog posts aimed at explaining the models.

In these three SAP activities, the collected examples were drawn from project-based design work done outside of the learning environment by designers not involved in the learning environment. In these activities, students learned from comparing examples of the design work of professionals or hobbyists whose work was publicly available.

Insights on Feasibility and Learning

In the SAP activity model, the source of design work precedes the capture, selection representation, and use of design examples. As such, it determines what can be documented, represented, and ultimately compared to support learning. In analyzing the source of design work in seven SAP Activities, a number of potential implications of the choice of source emerged.

There are multiple sources of content to consider

One takeaway from looking across seven SAP activities is that there are different sources of design work to consider for the collection of design examples. The early Research Through Design (RtD) inquiries focused on co-research with students as a solution to the design research problem of designing for “seeing across projects”

based learning. This approach centered the work of students as the source of examples for analysis and comparison. As part of the collaborative nature of the Making and Mapping seminar, the project-based design work of the instructor (myself) was used as well.

In some SAP settings, it was difficult to use students' design work, and these constraints drove the use of alternative sources. For example, in the Possible Project Deck, students were looking for project inspiration before they had done their projects. As there was not yet work from the current learners to compare, we leveraged the prolific only documentation of the hobbyist maker community. In the Design in the Wild Activity, the timing of different course components made it difficult to use student work. The proliferation of design artifacts with interaction design components that students were exposed to in their everyday lives provided a convenient external source.

Like with the 'design content' feature, open-ended opportunities lead to new source considerations. For example, in the Possible Project Deck Activity, students used a few online sources for potential projects that I was not aware of.

These results provide a starting point for considering what sources of design work might be considered for capture to support learning by looking across projects. In seeing the sources used, many more spring to mind. For example, might we consider student work across different project-based learning courses, or might we have students draw on past design experiences as the source of examples? None of the SAP activities used both internal and external sources in the same collection. However, this is possible and might be useful for particular learning objectives. Future work is needed to better understand what kinds of sources or combinations of sources best support specific learning outcomes.

Source and Opportunities for Reflective Learning

A primary rationale for having students use their design work as the source of examples was to make it possible for them to reflect on their design work through comparison with the design

work of others. Turns and colleagues define reflection "as a form of thinking in which one actively and intentionally constructs meaning of past experiences in service of future action" [9]. In his "Reflection in Action" theory, Schon argues that reflection is a critical element of professional design activity [7]. One of the defining features of reflective thinking is that one reflects on one's own experience and knowledge [8].

In the four SAP Activities where students' design work was used as the source for examples, there were more explicit opportunities for students to reflect on their design work and design learning. In these activities, the self-documentation (capture) and representation of their design work provided opportunities for reflection. In addition, comparing examples that included their own design work allowed opportunities for students to reflect through comparison of their work to the work of others.

In the three SAP Activities where external design work was used as the source, for example, there were fewer explicit opportunities for reflection during the selection and representation of examples and in comparison of examples. Students were engaged in design work at the time of the activity, so they could have chosen to compare examples in the collection to their own work, but it was not an explicit part of the selection, representation, or use of the design examples. In two of these activities (the Project Possibility Deck and the Design in the Wild deck), students were asked to provide a rationale for why they chose these examples. This prompt likely engaged students in reflection. However, the object of reflection was the student's choice of example, not their own design work or design learning.

When considering the potential for reflective learning, using student work as the source provides more opportunities for reflection. When using external sources, it might be possible to support reflection through prompts that ask students to consider how these examples relate to their own work or consider mixing sources that include both student and external work. Future work is needed to better understand the relationship between the source of design examples and reflective learning outcomes.

Breadth of Examples Based on Expertise

Using the lens of Variation Theory to consider the potential for learning, we know that a certain breadth of examples is needed to create the patterns of ‘contrast,’ ‘generalization,’ and ‘fusion’ needed to discern critical aspects and features of a particular ‘object of learning.’ While different ‘objects of learning’ will have different ‘critical aspects,’ many objects in engineering design education require distinguishing expert practice from novice practice.

For example, in the Design Process Data Visualization SAP Activity, the learning objective was for students to recognize patterns of an expert (or good) design process and to be able to recognize patterns in their own design process. Given the principle of ‘contrast,’ for students to understand a good design process, they need to be able to contrast more and less expert design processes to distinguish the features that define a good design process. This suggests that for many ‘objects of learning,’ sources of examples must contain a breadth of expertise.

When looking at the sources across the seven SAP Activities, many did not have a broad range of expertise. In the four activities that sourced design work from within the learning environment, students were the main authors of the design work. These activities came from the third iteration of the Making and Mapping Seminar (M&M3a and M&M3b). Participation in this seminar did not require any prior experience with laser cutting or design, and as a result, nearly all students were novices in the required tool use and fabrication techniques. The class was made up of primarily undergraduate students in their first or second year, some undergraduates in their third or above, and one master’s student). Students came from a few different proposed departments, which meant there was some mix of experience across psychology, computer science, human-centered design, and informatics. Students likely had a range of design experience but were primarily novices.

In the Making and Mapping DRG, the two instructors engaged in design work, as well as the capture and representation of their own

design work. One instructor was a novice in the fabrication technique of laser cutting, and the other had advanced knowledge. Both had strong educational backgrounds in design thinking. Adding the instructor’s design work to the collection of examples provided a higher chance of finding contrast related to expertise in examples.

For the activities that used design content from external sources, it is difficult to assess the experience level of the designers and the range of expertise of the designs. For the Project Possibility Deck SAP activity, students drew from tutorials, blog posts, and online retailers. This lends itself to an intermediate range of hobbyist expertise. When looking at the example, students found there is a range of complexity levels of techniques. For the Design in the Wild SAP Activity, students primarily found professional products. While there is a range in expertise and quality of professional products, there is more likelihood to see expert design qualities. Compared to the student work, there was more chance to find design work completed by experts, but still a narrow range. For the Process Model Board Activity, students gathered from many sources that were aiming to educate, so they likely had a higher novice level of expertise. For example, some design process models from the Dubberly compendium are based on research or expertise in the field.

When considering the impact of the source of examples on learning potential, choosing a source (or sources) that provides a range of design expertise is more likely to provide the variance needed to open up objects of learning related to expert design practice. University project-based learning environments very often have a fairly narrow range of expertise. Consider, for example, first-year design experience of capstone design courses. Including teaching staff or reaching across learning environments might provide a broader range of design examples from which to contrast features of expert and non-expert design practice. This opens up yet another area for future design and research.

Source and Availability of Different Kinds of Design Content

Recall the different types of design content shared in the previous section: process, product, rationale, performance, experience, and process models. Another insight that emerged from the analysis of SAP activities was that certain kinds of design content were more readily available from certain sources. This has a potential impact on the choice of source for certain learning objectives.

SAP activities that sourced examples from students' and instructors' design work internal to the project-based learning environment had the opportunity to decide what kinds of design content to document and how to document them. However, in these cases, much time was often spent on documentation. For example, in the Project Update Meeting SAP Activity process, product, experience, rationale, and performance elements were captured.

In the SAP activities, where design examples were sourced from outside of the learning environments, we had to make use of what and how others decided to document. However, using others' documentation reduced the time and effort needed to document. In the three SAP Prototypes from external sources, there was a range in what could be seen based on the specific source. Nearly all sources included photos representing design products. The presence of the design process, rationale, performance, and experience varied depending on the source that was used for the particular example.

In both the Design in the Wild SAP activity and the Possible Project Deck SAP activity, students used images found online, often using Google image search. If no other documentation was used, these provided product knowledge based on what was visibly documented. In the Design in the Wild SAP Activity, students evaluated the performance of designs using the visual and Don Norman's interaction design principles. This was not part of the source documentation, but based on the photo documentation, students could annotate their critique of the design.

In both the Design in the Wild and the Possible Project Deck SAP Activity, students used commercial products. This included photos but

also had the possibility of product descriptions. This sometimes, but not always, included performance features.

In the Possible Project deck, students were looking for laser-cut projects in the domain of hobbyist Maker projects. There is rich documentation of such projects in the form of tutorials and blog posts. Many examples came from tutorials. These usually included assembly instructions, photos of the product, and digital design files used to cut material. Sometimes, these tutorials also included stories of iterations and changes, the rationale for certain design choices, testing of performance, and details about what it was like to design and make it. Some students found video tutorials on YouTube. These included similar types of design content but in a video medium.

In the Process Diagram Board SAP Activity, students used a variety of online sources. Many of the sources cited were articles intended to educate, so they contained explanations of the models. These explanations sometimes included examples of each step but not examples of the full design process as it played out in a specific project.

When considering the design representations outside of the learning environment. It may be hard to find consistent documentation beyond visual representations of the design products. However, some sources provide more information than others. For example, many blog posts and tutorials in the Maker community included descriptions of design products as well as design process, rationale, performance, and experience.

Selection: How were the examples selected for the collection and activity?

Another property of the SAP Activities that had potential implications for feasibility and learning was how examples were selected for the collection.

'Selection' refers to the methodology by which examples were chosen for the design collection from available traces of design. This feature is highlighted in the SAP model in Figure 6_5. In two SAP Activities, all examples were included, so no selection occurred. In two SAP activities, examples were collaboratively chosen by participants in the activity. In four SAP activities, examples were selected individually. In one case, this was by the instructor. In other cases, this was by participants in the activity. Figure 6_6 provides a summary of the methodology used for the selection of examples for the collection for each of the seven SAP activities.

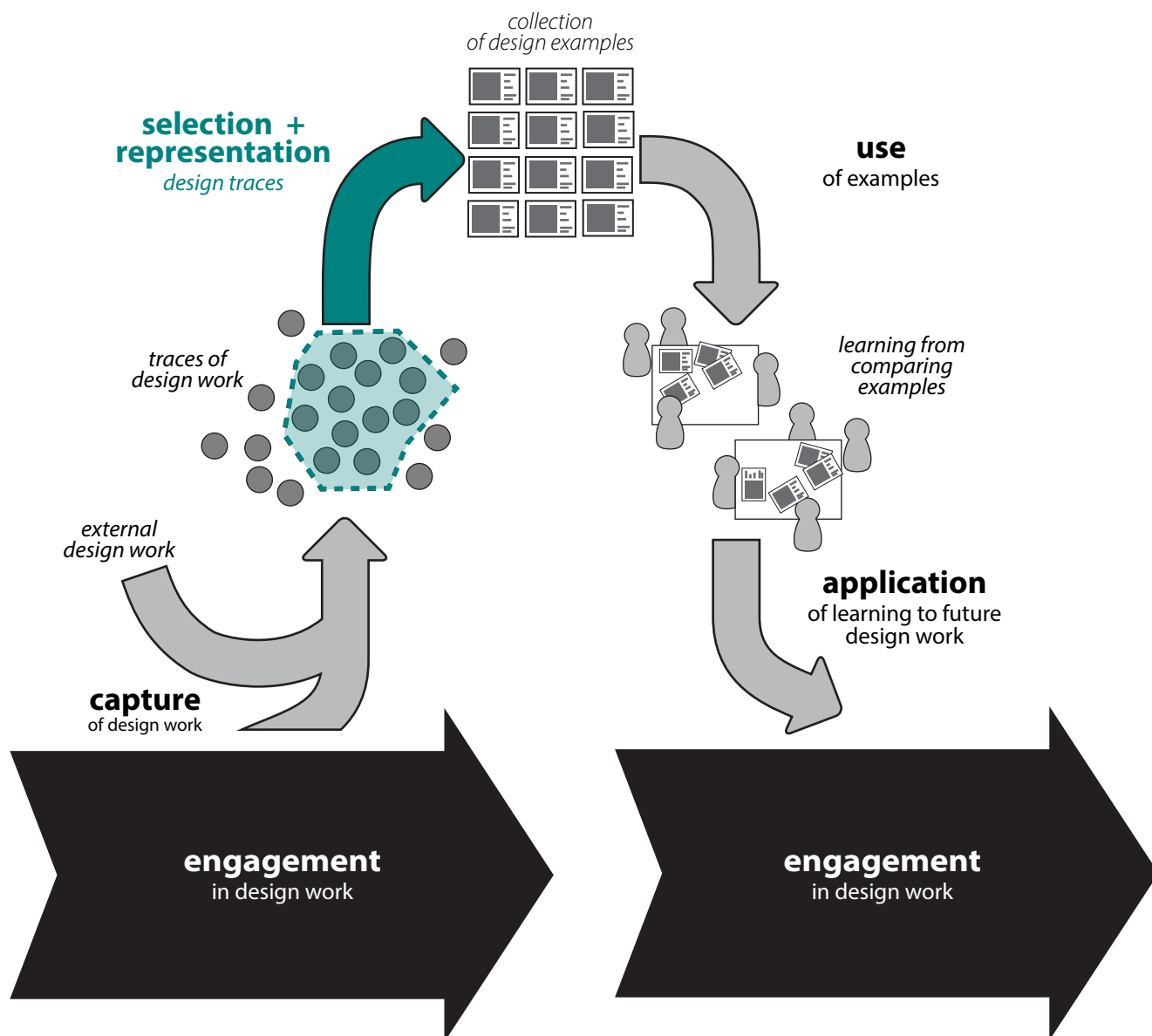


Figure 6_5: This figure depicts the six elements of the 'Seeing Across Projects' Activity Model: the engagement in design work, the capture of design work, the selection and representation of design traces, the use of examples, and application of learning to future design work. The feature of "selection of examples" as represented in the design collection is highlighted in blue.

Selection: Method of Selecting Examples for the Collection

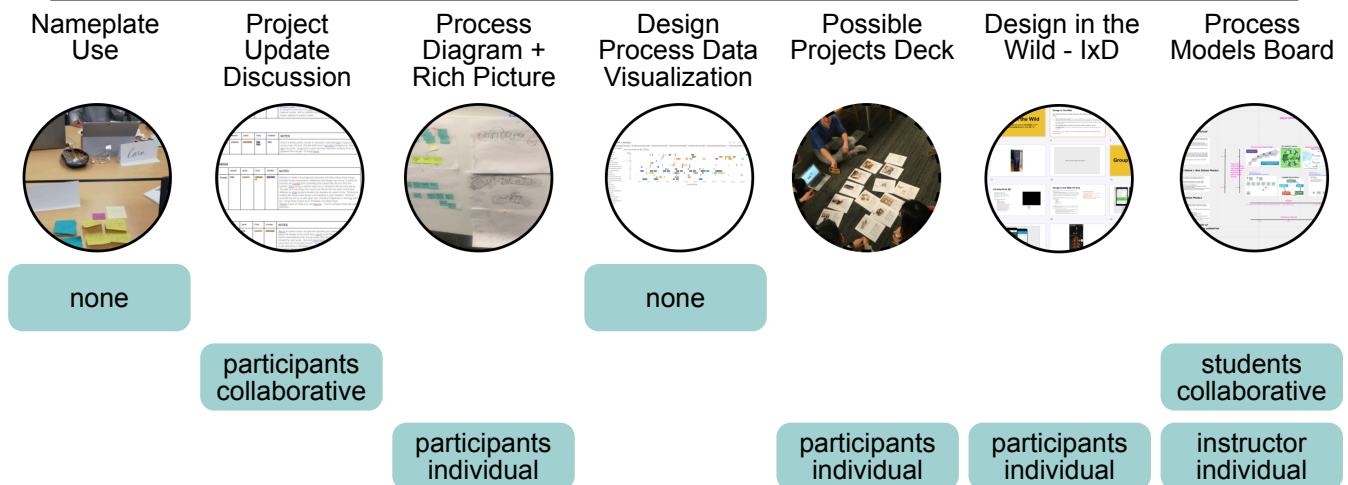


Figure 6_6: The figure above shows the different kinds of example selection methods identified in each SAP activity. The seven SAP activities are labeled and depicted from left to right: Nameplate Use, Project Update Discussion, Process Diagram and Rich Picture, Design Process Data Visualization, Possible Project Deck, Design in the Wild, and Process Model Boards. The 3 methods kinds of example selection (no selection, collaborative selection, and individual selection) are labeled below each SAP activity where they were present.

The following sections describe the three types of selection of examples used in the seven SAP activities and discuss the possible implications of those methods of selection on feasibility and learning.

Selection in the 7 SAP Activities

No Selection

In two SAP Activities (the Nameplate Use and Design Process Data Visualization), no selection of design examples from traces was made. All design examples of a specific type were planned to be used rather than a subset. Both of these activities used student work as the source of the design examples, so the intent of these activities was to use the work of everyone who had participated in the project within the learning environment.

The Nameplate Use SAP Activity occurred in the third iteration of the Making and Mapping seminar (M&M_3a). Students and the two instructors (myself and another graduate student) created at least two versions of a nameplate for use in the weekly seminar meetings. The first nameplate was made of folded paper, and the second version was created from wood as an introduction to the use of a particular tool (a laser cutter). Both

students and instructors were asked to bring and use their nameplates in the weekly group meeting. In this activity, no selection of specific final design artifacts to share was made. Each participant's paper and laser-cut nameplates were part of the collection.

In the Design Process Data Visualization SAP Activity, the focus was the design processes of students and one instructor (myself) as they worked on their ten-week personal fabrication projects in maker spaces on the university campus. The intent of this activity was also to use all of the participants' design activities rather than selecting specific examples. The design process was operationalized in this SAP Activity as patterns over time of all design activities a participant engaged in for a project. This meant we needed to capture all activities, not just a subset. Over the ten-week duration of the project, participants were to log and later code all periods of design activity. While the intent was to capture all activity, in reality, the difficulty of documenting and coding activity meant that students did more activity than they were able to record. However, all log data captured was included in the data visualization representation.

Participants Collaboratively Selected Examples

In two SAP activities (the Project Update Discussion and the Process Diagram and Rich Picture), a subset of design content was chosen collaboratively by participants in the course or seminar.

In the **Project Update Discussion** SAP activity, students selected what parts of their design work to share and discuss. This activity used students' ten-week projects as the source of traces of design, and the activity took place in a small group meeting with four students and one instructor (myself). Each student was given nine minutes to "talk about their project" and was given the freedom to "use the time however they like." However, instructions oriented the discussion towards giving and receiving feedback. Additionally, the individual reflection activity at the beginning of each meeting primed students to think about what they had worked on the past week, what they were struggling with or wanted help on, and what they were planning to work on the next week.

While students selected multiple examples from their design work to share throughout the discussion, the structure of the discussion activity made this selection collaborative. Each of the four students was assigned a role: Interviewer, Presenter, Note Taker, and Timer. The presenter was instructed to choose what to share and to use the time however most productive to them. The interviewer's role was to facilitate the conversation and encourage others to ask questions and share feedback. Questions and feedback were provided by the other students and one of the instructors (myself).

In the **Process Model Board Activity**, students selected process models collaboratively. In the Introduction to User-Centered Design Unit of the second iteration of HCDE 210, seventeen groups of students were asked to select representations of process models during the lecture near the end of that week-long unit. This lecture was conducted remotely via Zoom, and breakout rooms were used to facilitate student discussion in groups. Students were given two examples chosen by the instructor. Then, each group was

instructed to select two representations of design process models and two representations of non-design process models that were different from the two examples provided. Students selected representations from various resources, including the Compendium of Design Models from the Dubberly Design office, blogs, courses, and other online resources. How the groups of students selected the process model representations was left up to them.

Participants Individually Selected Examples

In the Process Diagram and Rich Picture SAP Activity, each designer selected four to six major activities from the past week of their design work. Like the Project update Discussion and Data Process Visualization, this SAP took place in the third iteration of the Making and Mapping seminar (M&M_3b) and focused on the design process of students and one instructor (myself) working on informal design projects in maker spaces on campus. In contrast to the Data Visualization Activity, where all design activity was included in the collection, in this activity, designers were asked to individually select what they thought to be their major activities from the past week.

In the Possible Projects Deck SAP Activity, participants also individually selected the examples they wanted to contribute to the collection. Recall in this activity that twenty-one students and two instructors searched for examples of things one could make on a laser cutter. Each participant was to individually pick two projects each week for the last four weeks of the quarter. The selection and representation of these examples occurred outside of the weekly group meeting as pre-work.

Finally, in the Design in the Wild SAP activity, participants again individually selected examples to represent. However, instructors engaged in the selection and representation of examples before the students to provide work examples to help guide students and save time. Recall that in this activity, examples of designs from one's everyday life were to be selected and critiqued using Don Norman's Interaction Design Principles. Prior to the weekly fifty-minute virtual meeting, the instructor (myself) and the teaching

assistant individually engaged in the selection and representation activity to refine instructions and provide some worked examples. During the meeting, students then individually had the option of selecting a new design example or using one the instructors had provided and annotated their own slide.

Instructor Individually Selected Examples

In the Process Model Board SAP activity, the instructor selected examples in a way that was more dominant than in past SAP activities. In this activity, groups of students were to select two non-design processes and two design processes of their choosing. However, they were also required to use one design process and one non-design process model selected by the instructor (myself). The design model selected by the instructor was the design process model used throughout the course. The non-design model selected was the scientific process. This was chosen because it was assumed most students were familiar with it from compulsory science education.

Insights on Feasibility and Learning

In the SAP activity model, the selection of design examples precedes the representation and use of design examples. As such, it determines what can be represented and ultimately compared to support learning. In analyzing the method of selection of examples in seven SAP Activities, a number of potential implications for learning and feasibility emerged.

Students' Involvement in Selection Has the Potential to Contribute to Additional Learning

The SAP model positions the use of the collection as the key site of learning through variation. However, when selection is viewed through the lens of Variation Theory, we see involvement in selecting examples has the potential to support students in learning through variation as well. Selection, in some cases, exposed students to more examples than were in the collection. Asking students to select also had the potential to engage them in noticing and comparing instances in order to pick one.

In the instances where students selected examples from external sources, participation in the selection of examples had the opportunity to expose students to more examples as well as engage them in comparing and differentiating in order to select from multiple alternatives. In the Project Possibility Deck Activity, students were asked to select examples of things that could be fabricated with a laser cutter. Students describe searching sites like Instructables, which organizes thousands of project tutorials, or articles like "150 amazing Laser Cutter Projects and Ideas to Inspire You" [1], which shared many projects to choose from.

In instances where students were selecting examples from their own design work, students were likely not exposed to more examples but were given an extra opportunity to compare examples they had documented and potentially notice new similarities and differences. For example, in Process Diagram and Rich Picture, students were asked to write down four to six "major" activities they engaged in during the past week. It is possible that to choose "major" activities, students had to consider some activities they ultimately decided were not as important. The prompt to consider what activities might be "major" had the potential to engage students in a comparison where they noticed new things even though the activities they had engaged in were not new to them.

In the seven SAP activities analyzed, students were asked to select examples because it was a quick way to gather a collection or to make it more likely that the examples in the collection were relevant and meaningful to the students. Considering selection as a site of learning through variation opens up future research possibilities to better understand how selection methodology might support additional learning through variation.

Novice Designers' Ability to Select

While there are potential feasibility and learning benefits to involving students in the selection process, there are some concerns as well. In many of these SAP activities, students were asked to select design examples so that they could learn by comparing them. However, students were sometimes unable to successfully identify

the design content they were asked to select an example of.

In the Design Process Board SAP Activity, students were asked to find examples of process models. However, a few of the non-design process models students selected were not processes, as they did not have a defined relationship between steps. In the Possible Project Deck SAP Activity, students were asked to find examples of design products that utilized a laser cutter. At least one student selected projects that contained materials that should not be laser cut. In the Design Process Visualization SAP Activity, students were asked to create traces of their personal design activities and qualitatively code them as specific design process activities. Supporting students in creating qualitative codes was so difficult that the instructor (myself) developed an additional set of codes and coded their log data so that it might be possible to notice design process patterns.

Applying the lens of variation theory, one explanation for the student's difficulty in identifying particular design elements is that they had not yet discerned the concepts they were being asked to identify. These cases highlight some critical aspects that students needed to discern (and thus accurately collect) for certain design aspects.

In the Design Update Discussion and Design Process Data Visualization activities, students described what they did each week on their project and used the vocabulary of some design process concepts such as iteration, brainstorming, or prototyping. However, students could not always identify their activity as a particular design activity. This suggests that the activities that make up the design process are critical aspects that students need to discern to learn the design process. As students had not yet generalized design activities to the context of their project work, additional critical aspects are also needed to discern each design process activity.

In the case of the Possible Project Deck activity, not all students could discern what made a design product recognizable or possible to fabricate on a laser cutter. In the Design Process Board activity, it was assumed that students were familiar with the concept of process and process models. However, students' identification of models

that did not represent processes suggests that there are critical aspects related to recognizing processes that students need to learn before they can understand design as a process. In these two activities, some students successfully identified the design examples being asked for. However, it is unclear how much students relied on search terms and labels such as "laser cut project" or "design process model" when searching for designs generated by others.

In considering potential opportunities and future work, the ability of students to select before they have discerned certain critical aspects and features of an object of learning should be considered. However, asking students to identify the object of learning early in the course or early in an activity could be a way of evaluating what critical aspects students have yet to discern so that they can be opened up. It is worth considering when search terms and labeling might help students find examples before they understand why these are examples of the object of learning. Future work is needed to better understand when it is beneficial for students to engage in the selection of examples and when this should be done by someone else.

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Chapter 7. The Framework

The variation theory of learning (VT) was identified as a productive lens for planning ‘seeing across projects’ based learning in design learning contexts. VT prescribes the patterns of variance and invariance that a learner needs to encounter to discern a certain object of learning. It does not, however, prescribe how to design learning environments that help enact these patterns. The annotated portfolio analysis of ‘seeing across projects’ activities resulted in a general model of SAP activities (Chapter 5). This chapter articulates a framework that leverages both variation theory and the SAP model to prescribe an approach to designing SAP activities.

Magana proposes seven types of frameworks in engineering education research based on their purpose and use: guiding focus (theoretical and conceptual), guiding methods (methodological and analytical), and guiding educational innovations (instructional design, pedagogical, and evaluation) [4]. Instructional design frameworks are defined as “design principles or models that guide the design of instruction or curricula focusing on what should be taught, in what order, and steps to follow to align instruction.” Pedagogical Frameworks are defined as “methods, activities, and guidance for the purpose of teaching or delivering instruction focusing on how something is taught.” This framework aims to provide both pedagogical and instructional design support by outlining five steps to consider in designing activities for ‘seeing across projects’ based learning using the pedagogical lens of variation theory in project-based learning (PBL) environments.

This framework’s aim is to help learning

environment designers plan a ‘seeing-across projects’ activity that leverages variation theory (VT) to help learners tackle troublesome concepts by both doing design and looking across multiple design instances. The framework assumes that you have a PBL learning environment already or are designing one. It does not provide support on how to create a PBL learning environment but instead, how you might add an SAP activity to it. What constitutes a PBL environment can be interpreted quite broadly. This might include formal instruction (first-year design or capstone course) but can also be applied to informal learning environments (maker spaces, after-school clubs, or co-curricular activities such as internships) where students are participating in self-directed projects. In short, this can be used by anyone who has access to examples of design and learners who are, or in the near future will be, doing design work.

The next section presents an overview of the framework, followed by a detailed explanation of each element. The explanation of each element describes key decisions and actions a learning environment designer will need to consider. A worked example is woven through the description of each element to demonstrate application in a specific context. This worked example is conceptual, not the result of enacting and testing the framework in a live learning environment. The example describes a fictitious instructor, Professor X, and the planning of a ‘seeing across projects’ activity for implementation in a capstone design course.

An Overview of the Framework

The framework is made up of five steps. Each step articulates a set of key decisions and actions related to planning a ‘seeing across projects’ activity to fit within a PBL environment. While the steps of the framework are presented in order, it is expected that iteration through these decisions and planning actions will be needed as they will inform each other. A diagram of the framework can be seen in Figure 7_1.

Step 1 briefly describes key aspects of variation theory used in this context. These are pictured in grey in Figure 7_1. An account of the core principles and application of variation theory can be found in Marton’s book [5]. The remaining steps mirror the SAP model (Chapter 5) and are reframed to connect the theoretical principles of variation theory and apply the insights learned from the depth-focused annotated portfolio. Each step is renamed to reflect the reframing and focus on the purpose of each step.

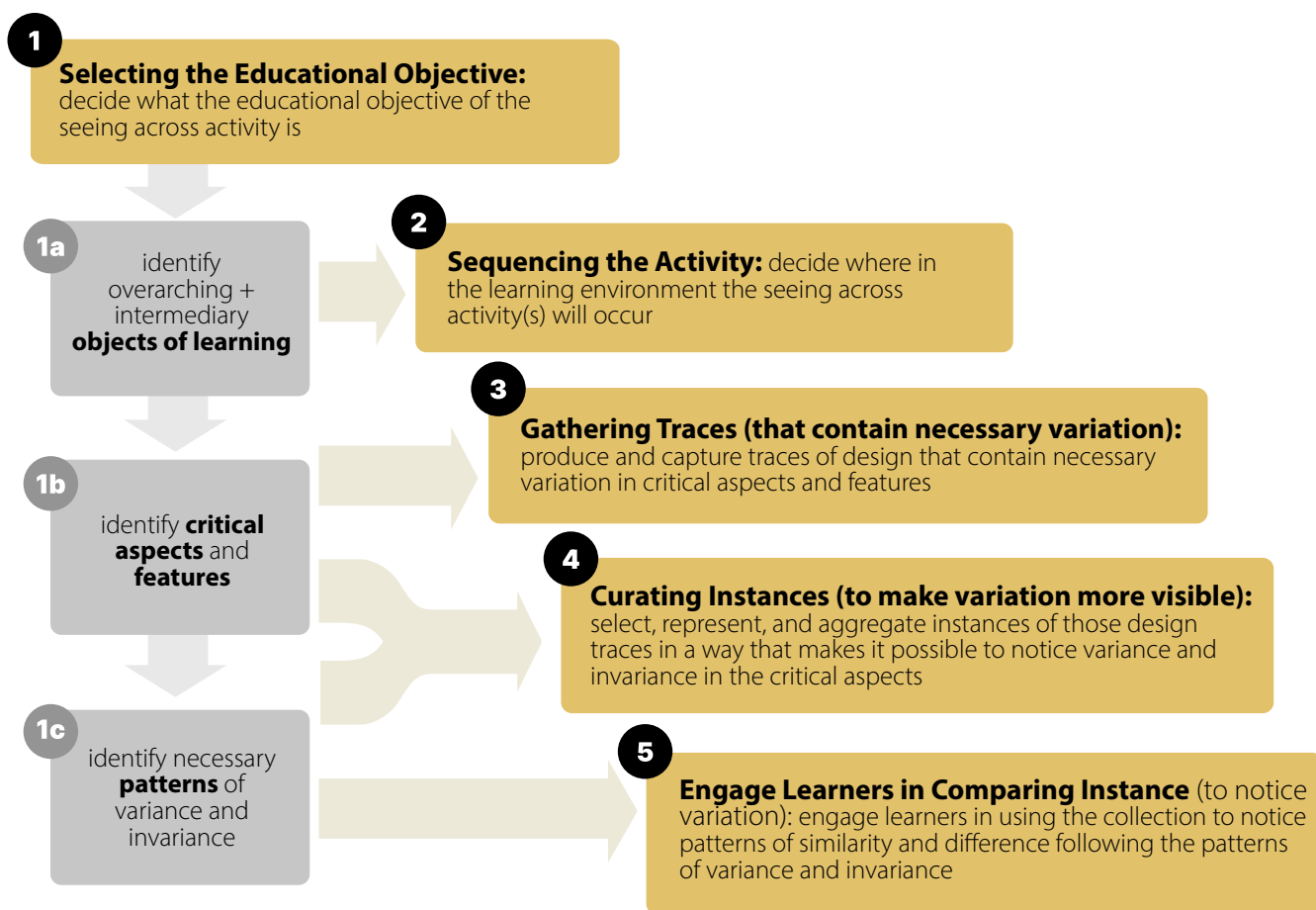


Figure 7_1: The figure above depicts a framework for designing ‘seeing across projects’ activities using the lens of variation theory. The framework is made up of five steps. Each is numbered and represented in yellow boxes. The grey boxes represent concepts drawn from variation theory. The first step in the framework is to select an educational object. This objective is then articulated through the core concepts of variation theory. First overarching and intermediary objects of learning are identified (1a), then critical aspects and features of these objects are identified (1b), and finally necessary patterns of variance and invariance are identified (1c). These sub-steps are identified by the labeled grey boxes. Arrows indicate that these are done in order. Next (2) the activity is sequenced. The intermediary objects of learning identified in (1a) are used to inform this step. Then (3) decisions are made about how to gather traces of design activity. This step is informed by the critical aspects and features defined in (1b). After that, the curation of these design traces is considered. This is informed by both the critical aspects and features and the identified patterns of variance and invariance in (1b) and (1c). Finally, the plan for exposing students to specific patterns of variation through the curated instances is made (5).

1. Selecting the Educational Objective

The first step in the framework is to decide the educational objective of the ‘seeing across projects’ activity (Figure 7_1 item 1). In variation theory, this is called the ‘object of learning.’ The object of learning dictates the variation learners must experience, which informs the subsequent elements of the framework. This decision is followed by articulating the learning objective through the core concepts of variation theory. First, the ‘object of learning’ is decomposed into ‘overarching’ and ‘intermediary’ objects of learning (Figure 7_1 item 1a). Next, ‘critical aspects’ and ‘critical features’ are identified (Figure 7_1 item 1b). Then, the necessary ‘patterns of variance and invariance’ for this ‘object of learning’ are laid out (Figure 7_1 item 1c). A full account of the principles of variation theory can be found in Marton’s book [5].

2. Sequencing the Activity

Next, it is important to decide where in the PBL environment to situate the ‘seeing-across projects’ activity. Intermediary objects of learning are aligned to the ‘seeing across projects’ activity (or activities if there are to be multiple). Other learning activities that may or may not contribute to the discerning of critical aspects and features should also be considered.

3. Gathering Traces of Design Work (that contain necessary variation)

To expose learners to variation through different design examples, one needs to have traces of various design work from which to choose examples with the right variation. In this step, the learning environment designer will make choices about the source of the design work and how the traces of that design work will be collected. The critical aspects and features will be aligned with these decisions to make sure the necessary variation will be present in the gathered traces.

This step mirrors the ‘capture of design work’ element in the SAP model. The word ‘gathering’ is used here to convey that traces of design and non-design examples may come from many sources and may already be documented.

4. Curating Instances of Design Work (to make variation more visible)

After gathering traces of design work that contain the necessary variation, the learning environment designer will curate the collection. The goal of this step is to organize the instances in a way that creates affordances for learners to notice differences when interacting with the instances. This may include selecting particular instances of design work, representing that work consistently, and choosing a means of aggregating the instances to afford seeing patterns of variation. Alignment with the identified critical aspects and features and the outlined necessary patterns of variance is key here.

This step mirrors the ‘selection and representation of design examples’ element of the SAP model. The word ‘curating’ emphasizes the need to organize and select particular instances to enact the particular patterns of variance and invariance (contrast, generalization, and fusion). The word ‘Instances’ is used to reflect that examples of non-design may be needed to support particular objects of learning.

5. Engaging Learners in Comparing Instances of Design (to notice variation)

Finally, the organized collection of instances is used to engage learners in noticing patterns of similarity and difference following the patterns of variance and invariance outlined in variation theory (contrast, generalization, and fusion).

This step mirrors the ‘use of examples’ element of the SAP model. The word ‘comparing’ is used to emphasize the role of comparison in enacting patterns of similarity and difference needed for learning based on variation theory. The word ‘engage’ is used to signify that there is more going on than just the use of examples. While not addressed in this model, there is an opportunity to bring in other learning theories or pedagogy to support engagement in comparing examples (for example, cognitive load theory [8] or self-regulated learning [9]).

Selecting the Educational Objective

The first piece of the framework is about establishing what is expected to be learned from the ‘seeing across projects’ activity and expressing that in terms of the ‘object of learning,’ ‘critical aspects and features,’ and necessary ‘patterns of variance and invariance.’ These are key concepts in the Variation Theory of learning. While these concepts are outlined here in Chapter 2, see Marton’s book [5] for a more comprehensive description.

This section begins with a worked example of how the fictitious educator “Professor X” has worked through this step in the framework, followed by key considerations.

The Worked Example:

In this worked example, consider a fictitious instructor, Professor X. Professor X works at a large public university in an engineering department. She has been teaching the two-semester capstone design course for a few years. Enrollment is usually fifty to sixty students who are divided into twelve to fifteen project teams. Industry sponsors partner with the department to support projects for each team. The course is structured around several design milestones. Students attend a weekly lecture and then work on their project teams and with their sponsors. There is a presentation at the end of the course, where each team shares their finished product in a public presentation.

Professor X sees students struggling with certain concepts each year. She’s not sure how to pack any more into an already crowded curriculum but is intrigued by the idea of helping students learn by comparing their projects. Historically, she has noticed that when students informally share what they are working on with other teams, they value it. She wants to implement a ‘seeing across projects’ activity in her capstone design course next year. It’s the beginning of the summer, and the next iteration of the course is right around the corner, so she begins brainstorming and planning.

Selecting the Object of Learning

Professor X thinks about the concepts students commonly struggle with in the capstone course. In past experiences in teaching the course, she has noticed students struggling with the open-endedness of project-based learning. While reading academic papers to better understand strategies for helping students deal with open-endedness, Professor X finds that ambiguity has been identified as a threshold concept in engineering education. This means it is both troublesome for students to learn and transformative to design learning. Doctor X decides to select the concept of “ambiguity in design” as the object of learning for this SAP activity she is planning. There are even a few phenomenographic studies outlining an outcome space of students’ reactions to ambiguity that she can use as a starting place for understanding.

Expressing it as an educational objective

With a worthwhile ‘object of learning’ in mind, Professor X considers the educational objective. If the topic of learning is “ambiguity in design,” what does she expect students to be able to do as a result of their learning? From the literature, Professor X learns that experienced designers react differently to ambiguity than novices. She settles on the educational objective that “students will develop more expert ways of reacting to and dealing with ambiguity in the design process.”

However, when she tries to identify ‘critical aspects’ and ‘features,’ it becomes clear that the ‘object of learning’ is perhaps too big and needs to be broken down into ‘intermediary objects of learning.’

Breaking it down into intermediary objects of learning

To “develop more expert ways of reacting to and dealing with ambiguity in the design process,” there are some other skills and concepts students must learn. Professor X uses the knowledge from the research she found and the knowledge gained from teaching this course to consider intermediary objects of learning. To develop more expert reactions to design ambiguity, students need to recognize that they can change their reactions. To do this, they must recognize that

Defining the Object of Learning

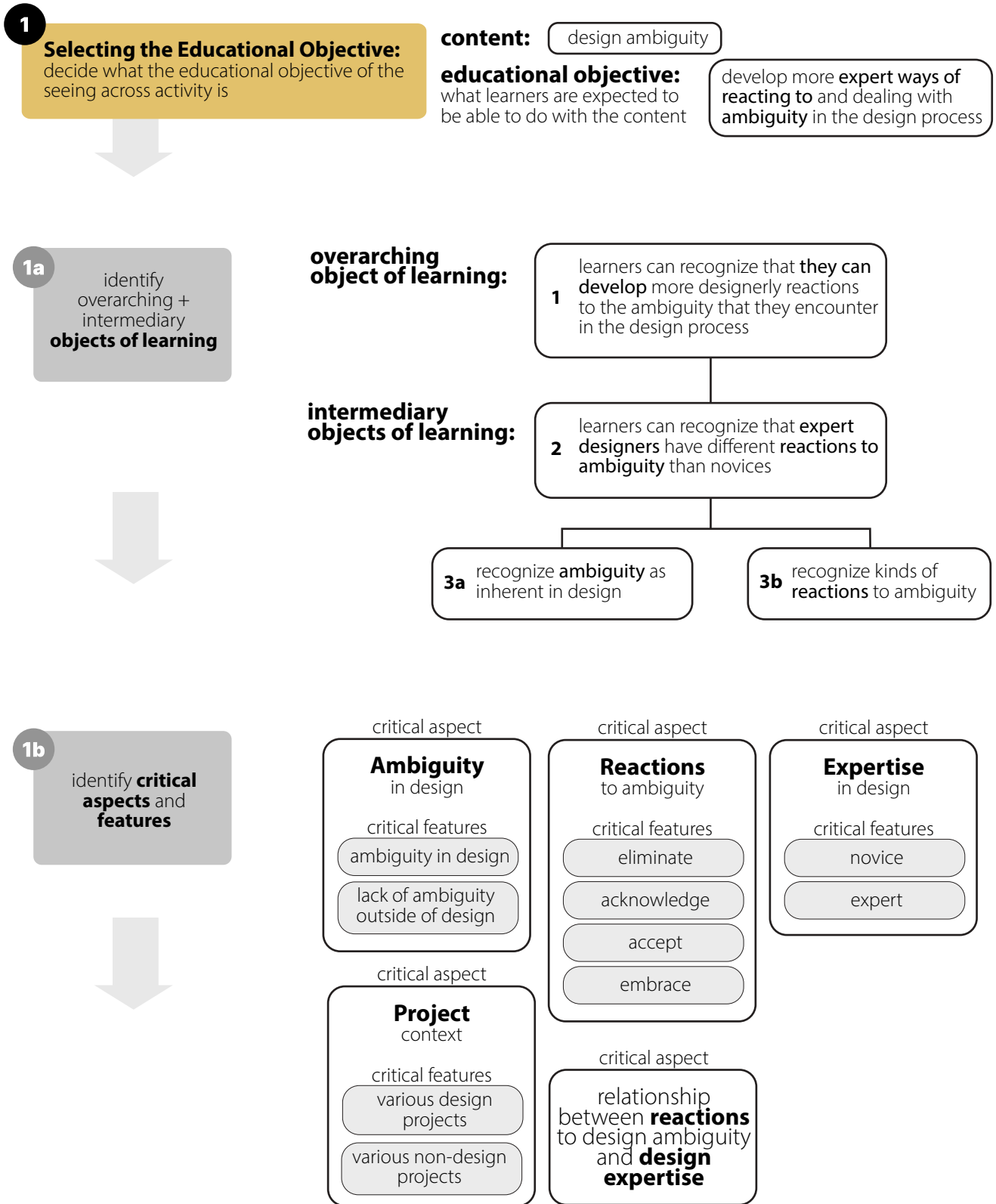


Figure 7_2: The figure above visually depicts steps 1a and 1b of the framework as applied in the worked example of Professor X planning an SAP activity to use in her capstone class. The object of learning expressed in terms of content, and educational objective can be seen at the top of the diagram. In the next section (1a) this objective is seen decomposed into intermediary objects of learning. At the bottom of the diagram (1b) the same object is expressed in terms of the critical aspects and features of the object of learning.

expert designers have different reactions to ambiguity in design. Finally, to do this, students need to understand different kinds of reactions to ambiguity and understand that ambiguity is inherent in the design process. Given this, Professor X decomposes the larger objective into intermediary stepping stones. These intermediary objects of learning can be seen in Figure 7_2.

Identifying Possible Critical Aspects

Next, the 'critical aspects' and 'features' needed to discern these 'intermediary objects of learning' are identified. While Professor X has taught the capstone for a few years, she has not formally had students document reactions to or encounters with ambiguity. So, it is not clear from past experience what aspects might be critical. However, Professor X was lucky to have found a phenomenographic

study that defined some of the critical aspects and features of student's encounters with ill-structured problems.

Professor X defines five aspects: Ambiguity in design, reactions to ambiguity, expertise in design, design projects, and the relationship between expertise and reactions to ambiguity. These aspects and features of these aspects are outlined in Figure 7_2. Some of these are critical because they are defining features. For example, ambiguity is a defining part of design and open-ended problem-solving. Additionally, experts have different reactions to design ambiguity than novices. Some of these aspects are critical because students must understand that they are not defining features. For example, ambiguity can be encountered in any design project. Professor

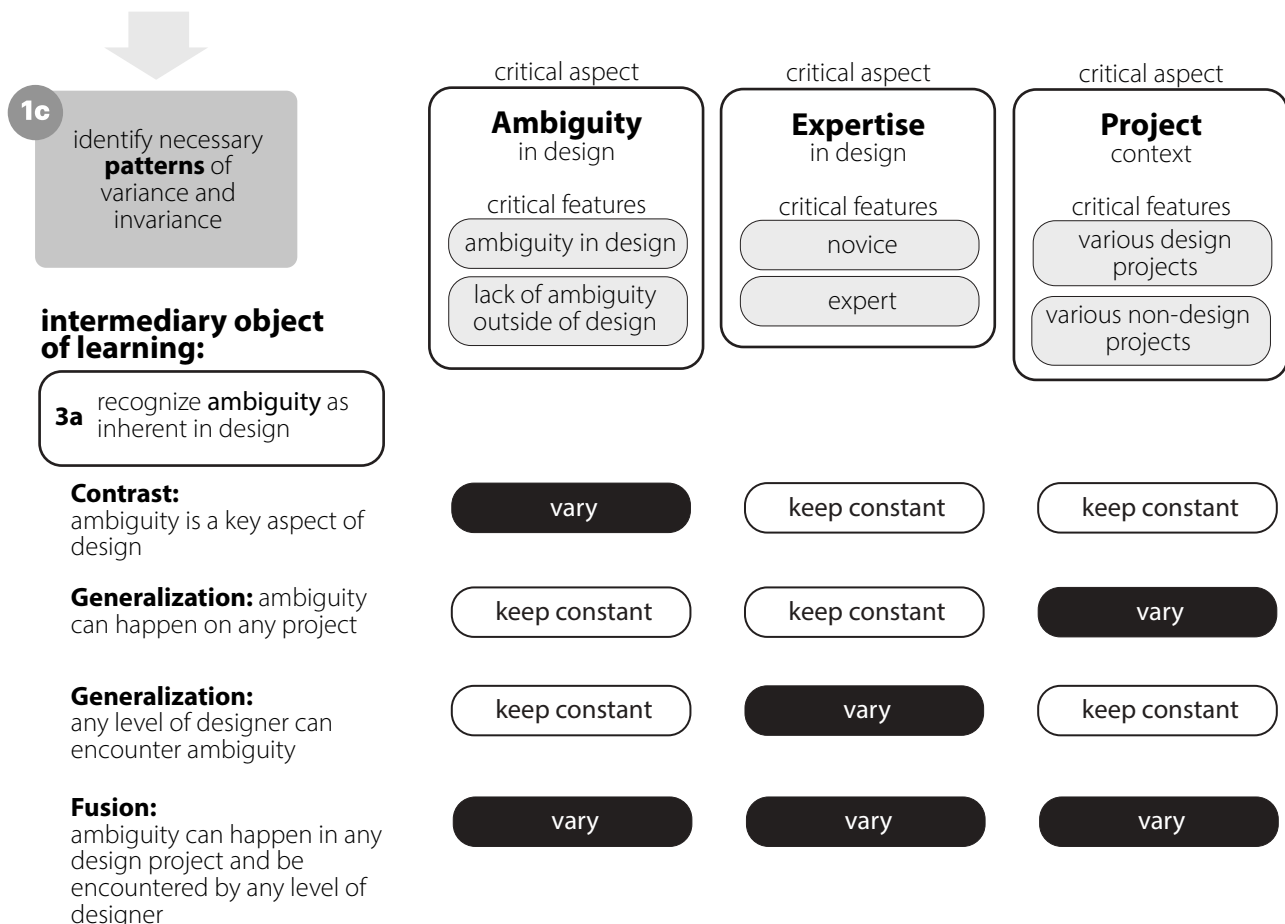


Figure 7_3: This figure shows step 1c from the framework applied to the worked example of Professor X (continued from Figure 7_2). The aspects of ambiguity, reactions to ambiguity, expertise, and projects can be seen depicted left to right across the top of the figure. Below are four rows representing the order of patterns contrast, generalization, generalization, and fusion. For each row, it is indicated if the aspect is varied, invariant, or not present for that pattern. For example, the first row shows that to enact the pattern of contrast for this object of learning, the level of ambiguity needs to be varied so that students see ambiguity in design and lack of ambiguity. To make this contrast, everything else should be held as invariant as possible. As indicated above, these examples where ambiguity in design varies, should keep the expertise of the designer invariant.

X anticipates that more critical aspects will be uncovered during the implementation of this activity and will be noted for future iterations.

Identifying necessary patterns of variance and invariance.

Finally, Professor X needs to identify the necessary patterns of variation that will be needed to help students discern each intermediary object of learning. These patterns will then be used to design the comparison of examples as part of her 'seeing across projects' activity. The suggested sequence of patterns of variation is 'contrast,' 'generalization,' and then 'fusion.' The expected patterns of variation Professor X outlined for the first intermediary object of learning, "recognize ambiguity as an inherent in design," is outlined in Figure 7_3.

the framework offers three key considerations to consider when choosing an object of learning. These considerations include the importance of the topic to be learned, the scope, and the feasibility of identifying 'critical aspects.'

Importance: Do I need to focus more time and attention on this 'object'?

The object of learning should be something that is important but difficult to learn. Taking time to help students separate and fuse critical aspects through patterns of variation is resource-intensive. Consider an object of learning for the 'seeing across projects activity' that students have struggled to learn in past iterations of your learning environment. Another method for choosing a worthwhile 'object of learning' is to use something identified as a 'threshold concept'[6, 7] in the field.

Considerations

Based on the literature and what was learned from the Annotated Portfolio (AP) of SAP activities,

In the example, Professor X selected "designerly reactions to ambiguity in the design process" as the intended object of learning both because she

Sequence

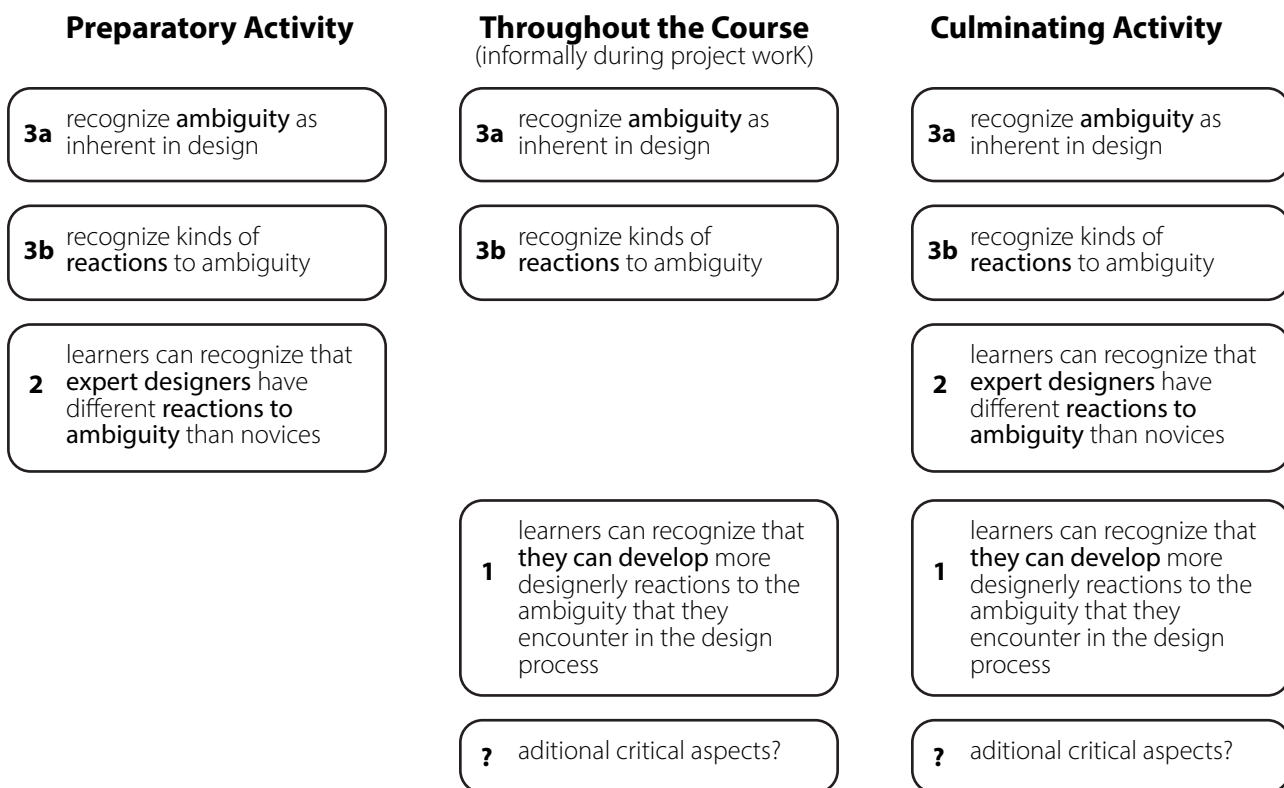


Figure 7_4: This figure shows step 2, 'sequence', from the framework applied to the worked example of Professor X. This figure takes the intermediary objects of learning, defined and shown in figure 7_2, and depicts how Professor X has sequenced the learning objectives across an initial 'seeing across projects' activity, the project work, and a culminating 'seeing across projects' activity.

has noticed students struggling with tolerance of ambiguity and design uncertainty and because this topic has been identified as a threshold concept in design education.

Scope: Is the scope of the ‘object’ too broad for the resources I have?

The scope of the object of learning should be matched to the resources available to spend on patterns of variation. Choosing an object that is important but broad (has many critical aspects to separate and fuse) may be difficult to enact. Breaking down the intended object of learning into ‘intermediary objects’ is a good strategy for dealing with larger objects of learning. This allows you to focus on intermediary objects that can act as ‘stepping stones’ along the way to the broader ‘object of learning.’

In the example, Professor X chose “develop more expert reactions to ambiguity in the design process” as the educational objective. However, when she saw that this was too broad, she labeled it as an “overarching object of learning” and identified three possible stepping stones that needed to be discerned to achieve that educational objective. These stepping stones were to recognize ambiguity as inherent in design’ (3a), recognize kinds of reactions to ambiguity (3b), and recognize that expert designers have different reactions to ambiguity than novices (2) (See Figure 7_2).

Finding Critical Aspects: How feasible is it to identify the ‘critical aspects’?

Recall that ‘critical aspects’ are not chosen but must be discovered. Knowing what might be critical aspects for your learners is essential to organizing the patterns of variance and invariance needed to support learning. Phenomenography and learning study research methods are used to uncover ‘critical aspects’ of an object of learning. As these methods are not yet frequently used in engineering design education, you will not always have the luxury of finding known critical aspects from the literature. However, evidence of what some students have learned and other students have not can help you determine what might be critical aspects. Recall that critical aspects are the dimensions students need to understand as being essential to or not essential to the object

of learning. There will also likely be individual differences in what students have learned to see. Looking at any pre or post-evaluations and individual differences, you may be able to identify some of the critical aspects.

Sequencing the Activity

Next, it is important to decide where in the PBL environment to situate the ‘seeing across projects’ activity elements. Some options for sequencing include before students engage in projects, after project work is complete, throughout the design process, or alongside the design process. Intermediary objects of learning are then aligned to the seeing across activity (or activities if there are to be multiple) and any other activity where students may encounter significant variation in the critical aspects. This supports the consideration of how other learning activities may or may not contribute to the discerning of critical aspects and features.

The Worked Example

Now that the ‘intermediary objects of learning’ and ‘critical aspects’ have been identified, Professor X considers the sequencing of these ‘objects of learning’ in the capstone course. Professor X plans to enact two looking across activities - a preparatory activity at the beginning of the course and a cumulative activity at the end of the course. She also expects that during the experience of making, students will encounter variation in critical aspects as well. The intermediary objects of learning that Professor X intends to design for are articulated in Figure 7_4.

The purpose of this preparatory ‘seeing across projects’ activity will be to prepare students to encounter ambiguity in their projects. This activity will occur before students begin their projects, and it will address intermediate objects of learning: 3a) recognizing ambiguity as inherent in design, 3b) recognizing different kinds of reactions to ambiguity, and 2) recognizing that expert designers have different reactions to ambiguity than novices.

Professor X expects that, throughout the project work, learners will encounter additional critical aspects that support the discernment of ambiguity (3a) and reactions to ambiguity (3b). Hopefully, they also begin to notice that they can develop different reactions to ambiguity (1) as their reactions change over time or if team members react differently to the same situations.

The purpose of the cumulative looking across activity will be to help students discern additional objects of learning that came up during the project work and reflect on their encounters with ambiguity to further understand that they can become more designerly in their reactions to ambiguity. In addition to addressing 'object of learning' 1 and 2, Professor X wants this activity to address additional critical aspects of 3a and 3b that emerged through students' project work. A visual of the sequence can be seen in Figure 7_4.

Considerations

Based on the literature and what was learned through the annotated portfolio analysis of SAP activities, this framework offers two considerations to take into account when sequencing 'seeing across projects' activities. These considerations include both the goal of the activity and the feasibility of gathering and curating design examples.

Supporting project work: Is the activity supporting current or future design?

As students work on their projects, they will likely encounter variation in the object of learning that could open up additional critical aspects. However, this variation may not be organized or complete enough that students are able to fully discern these aspects. There are two roles of the sequence to consider. When the SAP activity is done before the student's project work, the activity can help students see or do their project work in new ways. If done after project work, it can help students learn things they didn't have enough variation to learn through engagement in one project. Carrying out an SAP activity at the end of a project can help with future learning. One consideration of sequence is: Do you need students to understand a concept so they better carry out their project work, or do you want students to better understand a concept by

reflecting on their project and preparing for future learning? We see in the worked example that Professor X has chosen to incorporate an activity at the beginning of students' project work and at the end.

Feasibility: How feasible will it be to gather and curate design examples at that time?

Another consideration when sequencing the SAP activity is the feasibility of gathering and curating design examples at a particular time. If you are planning an activity at the beginning of a course, determine if you have a means of gathering examples beforehand. If you are planning an SAP activity during or after students have finished their projects, consider if you will have the resources to capture and curate these examples in real time based on the structure and timing of different components of the course.

Gathering Design Traces (that contain necessary variance)

The next step in the framework is to gather a collection of design traces to capture the necessary variance needed to help students discern the object of learning. The assumption here is that you may need to collect or gather more information than you need and then curate and represent what will aid students in seeing the appropriate patterns of similarity and difference. The object of learning you have chosen will dictate what kinds of design work you are looking for.

There are three key decisions to make in this stage. The first is about content - "What design work will be used to gather examples of variance?". The second decision is about the capture method - how to capture traces of the design work. The third decision is about what source (or sources) of design work to use.

The Worked Example

Now that Professor X has selected an educational objective and chosen where in the capstone class to sequence the two 'seeing across projects'

activities, she turns her attention to planning how to gather design traces.

The preparatory SAP activity planned for the beginning of the course will occur before students begin their design projects. Professor X plans to use documentation of past capstone projects, the phenomenographic study on ambiguity, and other published literature related to project-based design courses to find examples of ambiguity and reactions to ambiguity on projects with varying expertise. A potential source of contrast is examples of non-design projects that have very little ambiguity. Professor X expects she may be able to ask students to recall and bring up such experiences during the activity.

In last year's iteration of the capstone course, Professor X added reflection prompts at the beginning of the weekly lecture. Students spent the first five minutes of class individually answering a reflection question in a personal reflection journal. The professor found that this practice helped students consider what they were learning through project work and helped ease the transition into the lecture.

For the cumulative looking across activity at the end of the course, Professor X plans to use examples drawn from students' design experiences in the course. She wants them to reflect on how their experiences might have changed over time and to see what their peers experienced.

Professor X plans to leverage the reflection time in course lectures to have students consider their encounters with and reactions to ambiguity in their capstone project work. She decides to have students reflect on this five or six times throughout the two-quarter course so that changes over time might be captured. These prompts will ask students about their past experiences with non-ambiguous experiences and with recent experiences of ambiguity in their project. It will also ask them about changes in how they reacted to encounters with ambiguity and their reactions to these encounters.

In considering the critical aspects and features identified in step 1a, Professor X wonders if there will be enough variation in ambiguity and reactions

to ambiguity to create the needed patterns of variance and invariance. The capstone course has ties to industry sponsors and teaching staff, including graduate student teaching assistants. Professor X begins to plan how she might involve these folks with more expertise and diverse design project experiences in also responding to reflection entries about encounters with and reactions to ambiguity. The Professor even considers how partnering with a first-year design course and engaging them in the same reflections might provide a broader range of reactions to ambiguity to capture and consider in the SAP activity.

Considerations

As with the other steps in the framework, there are several practical considerations to take into account when planning how to gather traces of design work.

Expertise: Whose design work are you collecting, and what does it mean for variation?

Whose designs are in the collection has ramifications on the level of variation in the collection. To get enough variation to open up critical aspects specific to expert design practice, you may need to consider collecting examples from a set of designers with a range of expertise.

In the worked example, Professor X was concerned that student work might not provide enough variation in reactions to ambiguity. To ensure appropriate contrast between expert and novice reactions to ambiguity, Professor X is considering how she might extend the reflection activity to the teaching staff (including TAs and graders), project sponsors, and even a first-year design course. This would allow a set of examples that spanned different levels of design expertise.

Contrast: Are you collecting examples of things that are not 'design'?

As instructors, we often show examples, but it's counterintuitive to show examples of what something is not. If we are teaching design, we show examples of design, but we don't show examples of not-design. However, this is a core element of the variation theory. To understand a

critical feature that makes something what it is, you need to see an example of something with and without that feature. Consider if your design prompt allows enough contrast to see your object of learning.

In the worked example, Professor X realizes that students have lots of previous encounters with engineering science courses where design ambiguity is not present. Student past experiences with the lack of ambiguity in non-design situations are something that can be used as an instance to create contrast.

Feasibility to document

The source of design traces affects what elements of design can be documented. If student work is the source, it's likely that we can carve out time to have students document their experiences. If commercial products are the source, then it is significantly less likely that traces of the designer's experience are available. The feasibility of documentation is worth considering, particularly with regard to who is doing the documentation. Sometimes, the documentation you need to see the phenomena is not feasible to obtain. If you are asking students to document, consider that it's hard to document phenomena that they have not learned. Consider what content is already documented in assignments or the byproducts of the design work (like the artifact itself).

Curating Instances of Design (to make variation more visible)

The next step in planning a 'seeing across projects' activity is to curate the collection of design examples to make it more possible to create the necessary patterns of variation (contrast, generalization, and fusion) through comparison.

One element of curation is selection. You may have collected designs from a group of students or from publicly available documentation. It's likely that you may have more examples than are necessary. One choice you need to make is how many instances are necessary for students to look across.

Representation is another element of curation. This pertains to how each instance will be represented. Some means of representation include data visualizations, diagrams, photos of design artifacts, physical design artifacts, or text descriptions.

Aggregation is the third element of curation. Aggregation refers to how the instances might come together to be compared. You might, for example, create a hand-out where examples are arranged in a specific order. Here, you might consider how the representations of each instance might support learners in creating patterns by combining instances, shifting focus, or transforming the same instance. The idea of curation is further explored through the worked example in the next section.

The Worked Example:

Professor X has decided to gather traces of learners' encounters with and reactions to ambiguity through reflection prompts. In the prior step, she had also decided to try to collect reflections from first-year students, industry sponsors, and teaching assistants to ensure enough variation was present. She is now ready to consider how she might curate that collection of instances to create the patterns of variance and invariance that lead to learning.

To curate these instances, Professor X plans to partner with a research team that will qualitatively code the reflection responses. The number of responses and text format will make these instances time-consuming to analyze.

She plans to represent the instances in two ways: through a physical card deck and through data visualization. For the first two objects of learning in the sequence (discerning ambiguity in design and reactions to ambiguity), patterns of contrast generalization and fusion are needed. Professor X plans to select a small subset of instances that will best allow for the variance of one aspect at a time. Those instances will be represented on note cards containing a text quote from the reflection entry on one side and possibly another representation on the other side.

The last two ‘objects of learning’ in the sequence (understanding expert ways of reacting to ambiguity and understanding that one can change how they reacting to ambiguity) are about relationships between expertise, time, and reactions to ambiguity. For these, Professor X plans to use an interactive visualization to represent these patterns. This will allow students to interact with a large set of instances to see patterns across the whole class.

Key Considerations

Multiple representations and ‘generalization’

When considering representation, it is easy to assume that learners will understand what is being represented. However, the representations themselves have aspects that must be discerned by students. Multiple representations can support students in discerning aspects of the representation system and separating the concepts being represented from the representation [2].

If your representation of design instances is photos of artifacts, it is likely that students have discerned critical features of what makes a photo a representation. However, engineering design practice is filled with specific kinds of representations (3D models, sketches, diagrams, plots of performance data) that students may or may not have discerned.

In the worked example, Professor X plans to represent the student’s different reactions to ambiguity as categorical variables. She plans to use some kind of visualization to make it possible to look at relationships between many examples. The student’s experience, the quotes about reactions to ambiguity from the reflection entries, and the categorical variable are all different representations of one concept. Given this, the professor will need to ensure that students can generalize the concept of ‘kinds of reactions to ambiguity’ across the different representations.

Material and Tool Affordances: Does this material help me create patterns of variation?

Another consideration is what tools and

materials to use to represent the collection of instances. Different materials and tools will have certain affordances for creating patterns through combining instances, shifting focus, or transforming an instance. For example, digital whiteboard software (like Miro, Mural, FigJam, or LucidChart) could support combining instances by adding, removing, or grouping instances in digital space. It could support the shifting of focus through zooming in and out. Visualization software like Tableau could be used to create interactive visualizations from large sets of quantified instances. Instances could be transformed through different kinds of plots or encodings, or instances could be combined through filtering of data. A physical deck of cards could also be used to represent instances. Cards could be added, removed, or grouped on a surface to combine instances.

Engaging Learners in Comparing Instances (to notice variation)

After planning what is to be learned, timing, and how to collect and curate examples, the final step is to plan how you will enact the sequence of patterns of variation laid out in step 1c using the curated set of instances. There are three means of creating pattern variance articulated in variation theory: combining instances, shifting focus, and transforming the same instance.

Example

Professor X is now ready to consider how she might enact the needed patterns of contrast, generalization, and fusion (identified in step 1c) for each of the four intermediary objects of learning. She first considers structural constraints like timing and group size. She plans to engage students during the last fifty-minute lecture of the course. Students will work in groups of 3-5 with peers who were not on their project teams.

When considering how to control the patterns of variation, Professor X considers splitting the activity into four micro activities, each targeting one of the four identified intermediary objects of learning. The first two micro activities will follow

a similar structure to enact patterns of contrast, generalization, and fusion (in that order) for the “ambiguity” and “reactions to ambiguity” objects of learning. Teams will be given a small set of cards for each pattern of contrast or generalization. They will be instructed to lay out the cards, discuss what they notice, and then relate what they see to their specific projects. For the fusion pattern, students will combine the decks and draw three at a time, again discussing what they notice. At the end of each activity, groups will share back insights with the whole class.

The next two intermediary objects of learning (recognizing designerly reactions to ambiguity and noticing that they can develop more designerly reactions to ambiguity) are about relationships between ambiguity and expertise. These require fusion - varying of multiple aspects simultaneously. Professor X plans to use data visualization to represent and create these patterns of variation. She plans to have students interact with a data visualization dashboard in a program like Tableau. Students will be walked through adding and filtering to look at different groupings of expertise and reactions to ambiguity. The second activity will introduce the element of change in reactions over time.

Key Considerations

While there are many valuable considerations related to engaging learners in comparing instances, I point out two that surfaced in this work.

Structure: Have I imposed enough structure to enact the sequence of specific patterns of variation?

In many of the RtD prototypes, the activities were not highly structured. This made it difficult to enact both individual patterns of variation (contrast, generalization, and fusion) and the correct sequence of these patterns (as ordered above). Learners encounter and learn from variation outside of formal learning environments. However, the objective of enacting this sequence of specific patterns of variation with critical aspects is to make deeper learning possible.

In the worked example, Professor X wanted students to have some autonomy in actively

comparing examples but wanted to follow the specific sequence of patterns needed for the chosen objects of learning. She planned two levels of structure to support this. First, each of the four intermediary ‘objects of learning’ was treated like a micro activity, after which students brought insights to the larger group. This allowed for the sequencing of the intermediary objects. Additionally, within these micro activities, students were given prompts to move through in a sequence and had groups of different artifacts to use at each step. This allowed students to freely manipulate mini collections that contained controlled variance and invariance for contrast and generalization.

Group Formation: Is there a benefit to working in particular groups?

There are several variables to consider when choosing if students should work in groups or alone and how to form groups. From the standpoint of variation theory and what was learned from the SAP activities, groups can help support additional variance or invariance. Learners often have different past experiences related to the topic of learning that they can bring to the table as examples for comparison. One learning study found that students’ questions introduced new critical aspects into the activity [3]. Another study found that different learners’ ‘relevance structure’ influenced group problem-solving in physics [1]. Learners can bring additional instances or aspects that were not captured in the representations.

In the worked example, Professor X plans to have students work in groups of four with peers who are not on their project teams. This means that the students will be able to introduce information that may not be present in the instances represented on cards or data visualizations. If, during the discussion, aspects come up that were not represented, the students can compare similarities and differences across each of their projects.

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Chapter 8: Discussion

Considerations Regarding the ‘Object of Learning’

In this work, the ‘seeing across projects (SAP)’ activities enacted as part of four years of research through design (RtD) inquiry were generative and exploratory in nature. Many activities had broad educational objectives and aimed to see what might be possible to learn by comparing examples. They did not explicitly identify targeted ‘objects of learning’ or ‘critical aspects’ of these objects.

The variation theory of learning (VT)[20, 21] was found to be a fruitful lens for evaluating what was made possible to learn in various SAP activities (Chapter 6). However, to fully implement VT as an analytical or pedagogical lens, it is essential to identify the ‘intended object of learning’ and the ‘critical aspects’ for that concept and the learners. In the ‘seeing across projects through variation theory’ framework (Chapter 7), I have suggested how VT might be more explicitly leveraged to design future SAP activities. This includes identifying the ‘object of learning’ and at least some ‘critical aspects’ before planning and executing the activity.

However, choosing appropriate ‘objects of learning’ may be difficult in engineering design education. Core learning objectives are not well defined in engineering design education compared to other disciplines or the engineering sciences[28]. The signature pedagogy for design

teaching, project-based learning (PBL), engages students in doing design work, not learning a specific list of core aspects of design.

Additionally, once an ‘object of learning’ is selected, ‘critical aspects’ must be identified. Recall that ‘critical aspects’ must be found, not decided, and are relative to both the content and the learners. ‘Critical aspects’ are usually found through methods like phenomenography and learning study. There is limited phenomenographic research in engineering design education. The studies that do exist are on broad topics such as students’ experiences of “ill-structured problem solving” [7], human-centered design [37], workplace problem solving [27], sustainable design [6], cross-disciplinary design [6], and innovation [9].

Some Criteria for Consideration

How might we identify objects of learning in engineering design education that are worth further research? Literature and the work of this dissertation suggest some means of finding promising ‘objects of learning.’ I offer four criteria for consideration in choosing ‘objects of learning’: intermediary objects of learning [12], threshold concepts [22, 23], feasibility, and broad applicability. Using these criteria, I then suggest four promising ‘objects of learning’ we might consider as a community.

Intermediary ‘Objects of Learning’

The RtD prototypes described in this work addressed different design learning objectives related to topics such as design process, materials and fabrication, and interaction design principles.

However, many of these learning objectives were too broad in scope when viewed through the lens of VT. For example, a general goal of the Making and Mapping seminar was to help students recognize and execute patterns of an expert design process. While this is a highly important learning objective, I found that there were many critical aspects that students had not yet learned, making it too broad an objective for the time and resources available.

In other disciplines, researchers have advocated for breaking down broad objects of learning into their critical features and treating these critical features as a ‘stepping stone’ or ‘intermediary object of learning’ [12]. Fridberg introduces the terms “overarching object of learning” and “intermediary object of learning” to refer to this kind of decomposition [12]. Lo and Chik [19] refer to these concepts as “higher-level” and “lower-level” critical features, arguing that one can “break down what initially appears to be a too demanding object of learning into its critical features” and that “learning of the lower-level critical features will contribute to the grasping of higher-level critical features” [19]. For example, ‘intermediary objects of learning’ for the concept design process would include the different stages of the design process, such as ideation, and core concepts needed to understand the design process, such as iteration or divergence. By focusing on divergence, students could learn a stepping-stone concept that can support a better understanding of the design process in the future.

Threshold concepts

Variation theory requires significant time and effort to identify ‘critical aspects’ and to create the patterns of variance and invariance needed for learning. To justify this effort, it would be advantageous to identify ‘objects of learning’ that are particularly hard to learn and that students are not likely to learn from the engagement in design work.

In other disciplines, ‘threshold concepts’ [22, 23] have been used in combination with variation theory as a means of picking an object of learning worth spending time on. Akerlind, McKensie, and Lupton developed an “innovative method of curriculum design” based on combining threshold concepts with phenomenographic

research and variation theory [2]. In this model, threshold concepts are used to identify disciplinary concepts worth focusing attention on, and then phenomenography and VT are used with action research methodology to understand differences in student discernment and plan learning activities. Threshold concepts have been used along with variation theory in studies of higher education, including topics in clinical [11], physics [35], and law [1].

While there has been limited investigation of threshold concepts in design education [28], design ambiguity has been identified as an applicable threshold concept. Toleration of ambiguity and design uncertainty has been identified as a threshold concept in industrial engineering [25, 26]. Similarly, in chemical engineering, “dealing with and accepting open-endedness of problems” has been identified as a threshold concept [10]. The idea of uncertainty has also come up in other disciplines, such as physics [35] and law [1], as a likely threshold concept.

Other topics in design education identified as potential threshold concepts include broad categories such as tacit skills, domain knowledge, project management, engineering science, and tools and equipment [14] or even the concept of design itself [33]. User-centeredness and empathy for the user have also been considered threshold concepts in engineering design education [15, 29, 36]. The interpretive nature of the design process [28] and design abstraction were seen as potential threshold concepts in architecture [34].

Feasibility of making patterns of variation from student or community design work

Another key consideration in choosing an ‘object of learning’ is how feasible it will be to collect, represent, and use examples that will open up the needed ‘critical aspects’ and ‘features’ for that ‘object.’ Feasibility was a key perspective used in the Annotated Portfolio analysis because the capture and representation of examples took significant time and effort in many of the SAP activities.

In this work, the design process was a difficult 'object of learning' to design for. As described in Chapter 6, it took significant time and effort to document the design process in the Making and Mapping seminars. This is likely due both to the fact that it was an extra step on top of the learning and doing, but also because it was difficult for students to document 'critical aspects' and 'features' of an 'object' they had not yet fully discerned. Additionally, because the learners were novices, it was difficult to see the contrast between student work that would make visible features related to expertise. As described in Chapter 6, there are certain qualities of 'objects of learning' and 'intermediary objects of learning' that will be easier to see from collections of community or student design work.

Broadly applicable

The last criterion for identifying potential objects of learning to prioritize for future design learning research is broad applicability in design teaching. While many domain or topic-specific concepts are likely to benefit from 'seeing across projects' based learning, focusing on design concepts that are applicable across many contexts and disciplines of design teaching could support more applicable research.

Consider, for example, the Making and Mapping seminar described in this work. In the third iteration of this seminar, students were working on personal projects using laser-cutting as the primary fabrication technique and utilizing resources in the university's maker spaces. To carry out their design work, students needed to distinguish aspects that were specific to that fabrication technique. For example, understanding what materials can and cannot be cut by the machines and why or in what conditions. This 'object of learning' is specific to the tool and fabrication technique. However, understanding relationships and tradeoffs between fabrication tools, materials, and geometry could apply across many domains of engineering. 'Objects of learning' related to the design process, like iteration, would be applicable in many design learning domains as well.

Four promising objects of learning

Taking these four criteria into consideration, I offer four promising objects of learning for future design learning research: 1) tolerance of ambiguity, 2) convergence and divergence, 3) iteration, and 4) tradeoffs and design decision making.

Tolerance of Ambiguity

Dealing with open-ended problems and tolerance of ambiguity is seen as important to being a good designer [8]. Dealing with and accepting the open-endedness of problems is difficult for students to learn [10], and tolerance of design uncertainty has even been labeled a "threshold concept" in industrial engineering [25, 26] and chemical engineering [10]. Project-based learning and the inclusion of more PBL opportunities earlier in the curriculum have been used to support students in learning tolerance for ambiguity, but comparing examples of tolerance for ambiguity could help students better understand.

Tolerance for ambiguity is broadly applicable to project-based learning, as it is likely that tolerance for ambiguity will be encountered in nearly all PLB design coursework. In project-based design learning settings, the problems are by nature somewhat ambiguous and open-ended.

In settings where students are working on different projects over long periods of time (like capstone design courses), it is highly likely they will encounter different levels of ambiguity across projects and over the duration of the project. Chapter 6 reports that in the seven SAP Activities analyzed, students were interested in and were able to document their experience of engaging in design work. This suggests that reporting on experiences of ambiguity could be feasible for students to self-document. Additionally, we hope that throughout their project work or sequences of courses, students will develop better skills for dealing with ambiguity. This provides an opportunity within or across classes to see changes in learners' reactions to encountering ambiguity. For these reasons, PBL coursework generally holds promise for producing instances of ambiguity and reactions to it that can be used to produce patterns of variance and invariance and

open up objects of learning for all students, not just the ones who happened to notice the variance in their projects.

This topic has the advantage of having some phenomenographic evidence to help identify critical aspects of the object of learning. In a phenomenography examining the experiences of first-year engineering students working on “ill-structured problems on teams” [7], an outcome space was determined. One dimension of this space outlines a progression in students’ reactions to ambiguity, moving from eliminate to acknowledge, accept, and embrace. The things students needed to notice to progress along this spectrum are the critical features we need to help them notice. The outcome space also included another progression in consideration of context (know, coordinate, utilize, internalize).

Convergence + Divergence

The concepts of convergence and divergence are central to distinguishing design as a unique process. Numerous design process models illustrate convergence and divergence as key features of the design process. For example, the “Double diamond” design model features two diamonds representing phases of divergence and then convergence for both the problem and solution space [3]. Other models, like Nigel Cross’, illustrate gradual convergence over the course of the whole design process [5].

Due to the structure of project-based learning courses and the nature of design, seeing divergence is likely achievable in almost any PBL environment. Unlike many courses in the engineering sciences where students are solving the same problems and are expected to come to the same solution, in PBL settings, students may have the same problem and arrive at different valid solutions. There is also often an explicit ideation phase of a project where divergence may be most easy to capture and look across. Coursework in the engineering sciences that students have already taken or are concurrently taking is full of examples of convergence. There is also an opportunity for patterns of difference that leverage the divergence present in PBL courses in contrast to the convergence students have been exposed to in non-design settings.

There is little relevant literature to help identify critical aspects and features of the concepts of convergence and divergence in design. A promising area for future work would be to explore students’ and experts’ conceptions of divergence and convergence and what critical aspects of this concept might be for novice designers.

Tradeoffs + Design Rationale

Because design is open-ended, the concept of tradeoffs and their relation to design decisions and requirements is a key aspect of understanding and doing design work. Design rationale refers to the explicit articulation of decisions made during the design process and the reasons why those decisions were made [24]. It typically includes alternatives considered, trade-offs between alternatives, and the reasoning behind a certain design decision.

Over the three iterations of the Making and Mapping seminar, it was found that design decision-making and rationale for those decisions was a feasible design topic to capture in self-directed PBL experiences in maker spaces. Though not explicitly directed to do so, students all engaged in and were able to document many instances of design decision-making [30–32]. In the annotated portfolio analysis conducted as part of this work (Chapter 6), design rationale was seen to be feasible for students to document.

Additionally, design tradeoffs and design rationale are broadly applicable across many disciplines and domains of design learning. However, it is likely that the kinds of decisions being made and the design requirements (or success criteria and constraints) being considered may be domain-specific.

Iteration

It is widely recognized that ‘iteration’ is a key feature of the design process and supports better design outcomes. However, novice designers struggle with the concept [4]. In this work, it was found that while the concept of iteration may be difficult for students to grasp, it was feasible for students to self-document ‘edits,’ ‘adjustments,’ or ‘modifications’ of their design that could support the learning of iteration through examples.

Future work

To use variation theory as a pedagogical tool, 'critical aspects' and 'features' need to be found for the topic and group of learners. Phenomenography and Learning Study methodology are often used to uncover critical aspects [20]. A promising area of future work, if we are to better understand how variation theory can be applied to engineering design education and if we are to better understand the potential of 'seeing across projects' activities, is to conduct phenomenographic studies or learning studies on topics in design such as reaction to ambiguity, iteration, convergence and divergence, and tradeoffs and performance.

One of the realizations of this work is that each phase of the 'seeing across projects' activity can contribute to students' exposure to and learning through variation. Future work should validate what kinds of critical aspects students are already discerning from the making and what critical aspects of these objects would best be discerned through a 'seeing across projects' activity.

The Role of Open-ended Components

There were many open-ended components in the SAP activities. The open-endedness was partly due to the divergent nature of design itself: given a design problem, there are many potential solutions. However, in many cases, open-ended features were designed into the activities due to the exploratory nature of this work and the desire to provide student involvement. The instructor (myself) made some choices in the activities, but in many cases, students were invited to make choices as well. Sometimes, chance or other constraints of the project-based learning environment also contributed to open-ended components. Across the SAP activities, we see open-ended features in each element: engagement in design, the capture of design traces, selection and representation of design examples, and comparison of those examples to elicit learning through variation. The final SAP activities resulted from an ongoing effort to balance constraint and open-ended components.

Engagement in design always includes open-ended aspects. While the design problem and structure in a project-based learning (PBL) course constrain the space of possibilities, the nature of design itself means that there are many potential solutions for any given project. At the beginning of a PBL course, you don't know what students will create or exactly how they will create it. Decisions about engagement might include how structured the design process is, what problem students are solving, or the duration of their design project. How open-ended the design project was varied across the three iterations of the Making and Mapping seminar. The first seminar began by asking students to work on a project of their choosing in the university maker space. By the third iteration of the Making and Mapping seminar, the project scope was narrowed to at least three iterations of one project that was based on a tutorial and primarily used one rapid prototyping tool (this laser-cutter). In the end, each student created a different project and went about it in ways that were not prescribed. However, the narrowing helped make it easier to see design process activities across different projects because they used the same tools and a more limited set of techniques.

In planning the capture of design traces, there are a number of decisions to be made. For example, who is capturing, when are they capturing, how are they capturing, and what is being captured. In the SAP, the method of capture and what was being captured was sometimes left somewhat open-ended. In some iterations of Making and Mapping, students explored different methods of capturing design work as they were engaged in their projects. Students chose what to document and, to some extent, how to document, developing their own distinctive methods of capturing their design work.

The selection and representation of examples also included some intentional open-endedness. In the Possible Projects Deck SAP activity, some things were more constrained than others. Students were asked to find examples of projects that could be made with a laser cutter. The collection of examples was constrained to one fabrication technique but otherwise left open-ended. Over 100 unique projects were collected across the two sections of the seminar. In this same activity,

students were also able to choose the source of their design example.

In this SAP, students represented the examples they found on a digital slide in a slide deck. They were asked to include a photo of the design artifact, the material used, the rationale for choosing the project, and two other characteristics they noticed. The instructor chose to have students document the material used because it was relevant for considering design tradeoffs and was easy to determine from the photo documentation. The two other characteristics were open-ended and allowed students to include notable features besides material they noticed when searching for projects.

The Design Process Data Visualization SAP Activity and the Process Diagram and Rich Picture SAP activity provide another example of exploring the range of open-endedness in how examples were represented in the collection. These activities occurred in the same seminar, so the same design process was the topic of both representations. However, in the Data Visualization activity, students were given no freedom in representing their design activity data. The aim was instead to log data from each student consistently, and the visualizations represented activities and were determined by one of the instructors. In the case of the “Rich Picture” representation, students were constrained to one page for their diagram, but what they chose to emphasize from their design work and how they represented it was up to them and varied from student to student.

Finally, the comparison of examples from collections in different SAP activities also showed variations in how open-ended components were. In the Process Model Board Activity, students were given specific instructions outlining several steps to compare six examples. In contrast, the Possible Project Deck activity was much more open-ended. Students were asked to decide on a question they thought could be answered with the collection and then were asked to try and answer that question by comparing and organizing the collection of over fifty examples in any way they saw fit.

In many activities, the examples that students saw were determined by breakout groups that were

randomly assigned. Students compared examples of the students in the group rather than examples that had been specifically selected to bring out specific key features and aspects.

Rationale and Ramifications of Open-ended Components

Recall that most of the SAP activities were not designed from the principles of the variation theory of learning (VT). That lens was seen as productive and applied later. The research through design (RtD) inquiries were explorations of the solution space of SAP activities. Open-ended components were part of that exploration. While open-ended components had the potential to help surface new information or support student engagement, they also had some downsides.

In the analysis of SAP activities, it was found that some open-ended components helped define the boundaries of what SAP activities could be. For example, in the Possible Project Deck, students were asked to find examples of things that could be laser-cut. Several sources were suggested, but ultimately, students chose where they searched for and found projects. Students reported finding things on online resources that I was not aware of. Students were able to bring new knowledge of potential example sources. In the Project Update Discussion, students were given nine minutes to share project updates and solicit feedback or advice for future plans. The open-ended nature of this prompt helped bring to light an additional kind of design content: designer experience.

In some cases, the open-ended nature of components came from a belief that students’ involvement in choosing examples might support better engagement and learning. For example, in the Design in the Wild SAP activity, students were asked to pick an example of a design from their everyday lives to represent and critique. The reason for asking students to choose rather than providing examples was exploratory: to see what kinds of designs students might find and choose. However, it was also done with the expectation that if students chose examples, those examples were more likely to be meaningful, and students were likely to have some prior experience with them. VT takes into account

students' past experiences. What 'aspects' are critical is dependent on what the learner has already discerned from exposure to variance and invariance in the past. When encountering new examples, learners have an opportunity to compare them to past examples. While the SAP activity asked students to represent a product, in the critique of that example, it is possible that past experiences with that product informed their annotations. Future work is needed to confirm this hypothesis and better understand how students' choice of examples might support the leveraging of past experiences for comparison.

While there were some exploratory benefits of having open-ended components, there were some tradeoffs as well. One result of open-ended design collections was that different groups of learners had exposure to different examples and, therefore, exposure to different patterns of variance and invariance. Different patterns could lead groups of learners to learn different things.

For example, in the Possible Project Deck and Nameplate Use activities, students were divided into two sections of about eleven students. Each section created and used a different collection of design examples using the same methodology. The uniqueness of the collections meant that different things were possible to notice through comparison. For example, in the Nameplate Use activity, one included a greater variety of materials used than the other due to one student's use of acrylic plastic material. The variation in materials provided more opportunities to recognize material as a design choice and recognize critical features of material choice.

At worst, open-ended components may contain variation that leads students to make incorrect conclusions about the learning objective (object of learning). Take, for example the Design Process Board activity. Students worked in groups of about four in break-out rooms during a remote lecture. They were given two examples of process model representations and asked to find four more. They then compared these to notice what was different between design and non-design processes and what was different across the three design process models. One group noticed that all design processes have five steps, and non-design processes have variable steps. This

conclusion was true for the set of six models they happened to have in their group but not a broadly true 'defining critical aspect' of the design process. If we had stepped back to compare the number of steps in all of the models chosen by the seventeen groups of students (over fifty models), then it would have been clearer that both design and non-design models have a variable number of steps.

Open Questions for the Future

Open-ended components of the SAP activities have the potential to surface new possibilities and support students through relevance and the leveraging of past experience. However, if the variance and invariance present in the collection of examples are not carefully controlled, it can lead students to the wrong conclusions. This opens a number of questions for future research about the balance between open-ended components and curation.

When we add Variation Theory (VT) as a lens to the SAP activity model, the need for curated examples becomes clearer. Choosing a specific object of learning and identifying critical aspects and features provides guidance for the kinds of variance and invariance that need to be present in the collection of design (and, in some cases, non-design) examples.

VT prescribes the patterns of variation needed to discern certain critical aspects and features. It does not, however, prescribe how to create those patterns. Enacting patterns of variance and invariance is a design endeavor left up to the instructor or whoever else might be designing a learning environment. In many studies on the use of variation theory in the classroom, a 'learning study' methodology is used. In this methodology, groups of teachers and researchers work together to re-design lessons based on variation theory. This usually involves the teacher making decisions about what examples to use and how to use them to enact patterns of variance and invariance as part of lesson planning. There is little evidence of learning studies that use students' design project work as examples.

So what does this mean for the incorporation of open-ended components into "Seeing Across Projects" based activities? How might we leverage

the divergent nature of student projects or student-collected examples and still productively use them for learning through variation?

As articulated in the framework (Chapter 7), it is critical to identify an object of learning. Having a specific ‘object of learning’ allows one to determine the critical aspects and features of that object for a given group of learners. These ‘critical aspects’ and ‘features’ become a guide, dictating the kinds of examples required to create the needed patterns of variance and invariance.

In a study using VT to support the learning of 7th-grade mathematics, it was found that when students were not introduced to critical features in the lesson, students’ questions and the teachers’ answers brought in additional variation [17]. The result was that particular students’ questions had an impact on the critical features that were brought up and what was possible to learn. This study shows how curated examples by the instructor and open-ended questions from the students combined to help surface critical aspects.

One potential idea for striking a middle ground is to mix curation and open-ended components through several phases of SAP activities. Consider a project-based learning environment in which we design two instances of SAP activities: one at the beginning of a design project and one at the end. A small and curated set of examples and structured activity could be used at the beginning of the project to open up known critical aspects before students engage in making. As students work on their projects, they would encounter variation that we might not have been aware of or able to predict. Then, after the project is complete, a second SAP activity could be carried out to leverage the natural and somewhat unpredictable variation from students’ projects.

The framework in Chapter 8 prescribes a way to plan a ‘Seeing Across Projects’ activity. This work is grounded in Variation Theory and the empirical work resulting from the SAP model. However, the framework has not yet been validated through use. Variation Theory prescribes very specific and controlled patterns of variance and invariance. However, little research has considered the value of student-generated examples or the context of project-based learning. More design research

is needed to explore ways to balance open-endedness and constraint. More engineering education research is needed to better understand how different kinds of open-endedness affect learning.

Implications Beyond Higher Education

Much of this work is framed in the context of teaching engineering design in higher education. However, the design research question and pedagogical direction of ‘seeing across projects’ based learning is potentially far-reaching.

Consider the research aim of “How might we design environments that support learning from seeing across individual design experiences?” Here, ‘individual’ does not refer to individual designers but separate instances of design to be compared. These instances could be from individuals, design teams, or communities. While many of the SAP activities analyzed focused on individual design activities, a few activities used examples of team design projects.

Herbert Simon famously states, “To design is to devise courses of action aimed at changing existing situations into preferred ones.” Given this definition, ‘design experiences’ can be taken quite broadly as well. In this work, one of the learning environments focused on self-directed projects in campus maker spaces. Considering Simon’s definition of design, this could be expanded even more broadly to everyday design experiences. The ‘learning environment’ is also meant broadly. While a classroom is a learning environment, a community machine shop, workplace, or home might constitute an informal learning environment.

Koskinen notes that more substantial research results come from RtD research programs that repeatedly investigate the same design research problem [16]. For example, in the field of HCI, the Goldsmiths Interaction Research Studio has conducted a series of RtD inquiries into the topic of “ludic” interaction [13]. Over time, researchers from the lab and even other research programs [18] have addressed the same broad research topic in other contexts, enriching our knowledge

of ludic interaction. The SAP activities designed and analyzed in this work were carried out in two learning sites: an introductory design course and self-directed projects in a maker space accompanied by a seminar. A promising direction for future work is to approach this design research question in a variety of learning and design contexts to more deeply understand designing for 'seeing across projects' based learning.

The framework introduced in this work also has potential implications beyond higher education. The framework is designed to provide guidance for designing an SAP activity using principles from variation theory adapted to the chosen learning objective, learners, and context. Chapter 7 introduces the framework as intended for anyone who has access to examples of design and learners who are, or in the near future will be, doing design work.

While project-based learning (PBL) is often deployed in formal capstone or first-year design courses in engineering education, the use of PBL as a foundation for the framework can be taken broadly. This might include formal instruction (first-year design or capstone course) but can also be applied to informal learning environments (maker spaces, after-school clubs, or co-curricular activities such as internships) where students participate in self-directed projects. Communities working on co-design projects could consider how looking at collections of both design and co-design projects might help them better understand the principles of co-design. Teams within a workplace might consider how looking across projects with different team structures might help them understand features of good design team structure in their context. A promising area for future work is to test the framework in a number of different design and learning contexts and refine it to support different contexts of design learning, both formal and informal.

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Chapter 9: Conclusion

The field of engineering education research (EER) recognizes design as a topic that is important but difficult to teach and learn. The signature pedagogy for teaching design, project-based learning (PBL), has significant learning outcomes but is resource-intensive to design and implement. While there are arguments for integrating more PBL courses throughout students' education, this work argues for a complementary approach: 'seeing across projects (SAP)' based learning.

If we consider design experiences broadly, learners engage in design throughout their education, both in and outside the classroom. Additionally, in a design course, many individual or team engagements in design are collectively happening. While practices like peer critique or project presentations at the end of a course expose learners to other projects, there are limited systematic efforts to support students learning by engaging them in comparison or analysis of different design projects.

This work investigated the design research question: "How might we design environments that support learning from seeing across individual design experiences?"

Approach

This work used a three-phase approach to answer the research question with design research methods from the field of human-computer interaction research. First, the design and execution of the learning environments were viewed as RtD inquiries. Next, the annotated portfolio method was used to analyze many RtD

inquiries. Finally, a framework was developed by incorporating the empirical results of the annotated portfolio with the variation theory of learning.

A series of courses were designed and taught over four years. While each instantiation was unique, they were responses to the same broad design research problem of designing for 'seeing across projects' based learning. One site, 'Making and Mapping,' was a small research seminar. The whole course structure, as well as course activities, were designed by the author as an RtD inquiry. Three iterations of this seminar were analyzed. The second site, 'Explorations in Human-Centered Design,' was an introductory design course designed by two professors and taught by several instructors. In two iterations of the course taught by the author, specific activities within the course were designed and executed by the author as RtD inquiries.

The annotated portfolio method was used to synthesize across the many RtD inquiries at the activity level. The method was applied twice, once with a focus on breadth and again with a focus on depth. RtD inquiries were defined at the educational activity level and called 'seeing across projects (SAP)' activities. To further adapt the RtD methods to the engineering education context, the collection of design examples, the methods for creating it, and the methods for using it to support student learning were all represented in the portfolios.

The breadth-focused annotated portfolio reviewed documentation from the two learning sites (a

total of five courses), identifying over fifty ‘seeing-across projects’ activities. Each was named and represented with a signal photo, annotated, and analyzed.

The depth-focused annotated portfolio was used to better understand the different **properties** of the SAP activities and their potential for supporting learning or the feasibility of the activity. Seven SAP activities were selected based on the number of iterations, depth of documentation, diversity, and use. Each was represented by visuals depicting the collection of examples, what it took to get that collection, and how it was used. The annotations focused on learning opportunities and the feasibility of creating the SAP activity. In addition to capturing decisions and rationale, the variation theory of learning (VT) was used as an analytical lens to evaluate what was made possible by the enacted SAP activity. Synthesis of annotations surfaced many properties of the SAP activities. Three properties (content, source, and selection) were chosen for further analysis, resulting in a range of ways to implement each property and the potential implications of the property on learning or feasibility.

Finally, a five-step framework was created to guide the design of future SAP activities by aligning the empirical results of the annotated portfolio analysis to variation theory (VT). VT provides a lens looking at how learners appropriate objects of learning by noticing specific patterns of similarity and difference. VT prescribes the patterns of variation required for students to learn a particular ‘object of learning,’ but how those patterns are enacted is a design challenge for instructors.

Contributions

As discussed in Chapter 3, the contributions of design research methods are distinct from those in positivist or interpretivist research traditions. Stolterman characterizes scientific research as focused on the “existing” and “universal,” while design is in pursuit of the “non-existing” and the “ultimate particular” [6].

Design Artifact Contribution

In design research, the design itself (sometimes referred to as the ‘artifact’) is a contribution. Gaver and Bowers argue that specific concrete design examples play a more significant role in informing design practice than theory [1], referring to artifacts as the “definite facts” of RtD [2]. Stolterman argues that the “ultimate particular” in design has the “same dignity and importance as truth in science” [6].

This work offers a design artifact contribution in the form of two distinct SAP activities, the Design in the Wild activity from the Explorations in Human Centered Design course and the Design Process Data Visualization activity from the Making and Mapping seminar (Chapter 5).

Design Theory Contribution

Gaver and Bowers argue that theory by necessity under-specifies design [1, 2]. While design research aims to produce knowledge that can inform future research and practice, Gaver argues that we should expect design theory to be “provisional, contingent, and aspirational instead of extensible and verifiable” [2]. Annotated portfolios produce knowledge that is “intermediate level knowledge” [4], lying between generalized theory and design instances [3]. It honors the particularity of specific design examples while still drawing out broad and applicable features of the design or conceptual themes that may be generalizable to other designs.

This work offers a design theory contribution through the **SAP model** presented in Chapter 5. This model serves as a general solution to the design research problem outlining five key elements of the SAP activities produced. These elements were engagement in design work, capture of design traces, selection and representation of a collection of design examples, use of those examples to bring about student learning, and application of that learning to future design work. The SAP model situates an additional activity on top of project-based learning engagements. Further specificity is provided to the SAP model through the analysis of three features seen in Chapter 6 (content, source, and selection).

Each SAP Activity used a collection of examples to engage students in comparison. However, different activities collected different kinds of examples. Six different types of design ‘**content**’ were found across the seven SAP activities analyzed. This included the design process, product, process models, performance, rationale, and experience. Two insights that emerged from the annotated portfolio were that some types of ‘design content’ were more feasible to capture than others and that examples of things that are not design may be needed in the collections to generate patterns of ‘contrast’ needed for learning.

These results provide a starting point for considering what kinds of content can be captured to support learning by looking across projects. As each type of content is quite broad, future work is needed to explore areas of content within each type. Future work is also necessary to better understand the relationships between design content type, the capture method, and feasibility.

A ‘**source**’ for the design traces was chosen in each SAP activity. Two different types of design ‘sources’ were found across the seven SAP activities analyzed. This included sources internal or external to the design learning environment. Three insights that emerged from the annotated portfolio analysis were that the source had ramifications on opportunities for learning through reflection, the range of expertise and resulting opportunities for learning through variation, and the feasibility of capturing certain kinds of design content.

Each SAP Activity used a method of ‘**selection**’ to choose examples for representation and comparison. Three selection methods were found: no, individual, and collaborative selection. Two insights that emerged from the annotated portfolio were that selecting examples may provide opportunities for additional learning through variation, and students were sometimes unable to successfully identify the design content they were asked to select an example of. Future work is needed to better understand when it is beneficial for students to engage in selecting examples and when this should be done by someone else.

Methodological Contributions

Finally, this research provides a methodological contribution to engineering education research (EER) through the adaptation of the research through design (RtD) and annotated portfolio (AP) methodologies adapted from human-computer interaction (HCI) research. Few studies have explored how we might implement these methodologies in engineering education.

In the field of HCI, RtD was developed out of a need for a research method that respected the perspective and methods of designers. As innovative design artifacts precede theory about their effectiveness, there was a need to find ways of seeing design artifacts as research contributions. This work has argued that engineering education research is lacking in design research methodologies. These methods can help make space for the exploration and documentation of innovative educational methodologies and surface new directions for research.

This research provides a methodological contribution as an example of how RtD and AP can be used in EER. This work shows that RtD can provide valuable contributions, such as surfacing new pedagogical directions. Additionally, it provides an example of consideration of the different scales at which we might view the design of learning environments as research inquiry. Finally, it provides an example of how the AP methodology might be adapted to include critical elements of educational design that go beyond physical design artifacts seen in many APs in the field of HCI.

Framework

Instructional design, pedagogical, and evaluation frameworks help connect engineering education research to inform practice [5]. This research provides a research-to-practice contribution by developing a framework that combines the empirical results of the RtD and AP analysis with the theoretical guidance of variation theory.

This framework provides both pedagogical and instructional design support by outlining five steps to consider in designing activities for ‘seeing across projects’ based learning using the

pedagogical lens of variation theory in project-based learning (PBL) environments. As variation theory has seldom been used in engineering education or project-based learning contexts, this framework provides a means to support the use of VT in the field.

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New Pedagogical Direction

Through a series of RtD inquiries and analysis of these inquiries, this research has defined a new pedagogical approach to design learning in engineering education: ‘seeing across projects’ based learning.

Due to the exploratory nature of this work, there are significant areas for future design and empirical research. Empirical research is needed to measure how ‘seeing across projects’ based learning can add to the learning outcomes of a project-based learning course. Additional design research is needed to explore other directions for designing for ‘seeing across projects’ based learning in addition to exploring “ultimate particulars” within the variation theory aligned SAP Activity framework.

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