

Research Through Design: A Promising Methodology for Engineering Education

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Research Through Design: A Promising Methodology for Engineering Education (WIP)

Introduction

Engineering education research (EER) is a fairly young and interdisciplinary field. As such, a wide variety of methods and methodologies have been imported from both positivist and interpretivist traditions in other domains[1]. Design inquiry approaches, however, have yet to be widely adopted in the field. These research methodologies leverage design, not as a means of primarily solving a problem or generating an artifact, but as a means of surfacing theoretical knowledge. Given EER's roots in engineering, design inquiry approaches seem a natural fit and hold promise for opening up new research directions. In this article, we present a case study of how Research through Design (RtD)[2][3], a design inquiry approach from the interdisciplinary field of Human Computer Interaction (HCI), might be applied in EER.

Research disciplines rely on research methodologies to guide their work of knowledge production. These research methodologies involve procedures for doing work - such as collecting and analyzing data - and result in particular kinds of knowledge claims. Research disciplines often have methodological traditions that may represent the backbone of the work in a discipline. Occasionally, though, research disciplines proactively explore new methodologies in order to ensure the goals of the research discipline are being met. In advocating for the development of Design Based Research (DBR) in learning sciences, for example, Ann Brown [4] argues that the methods used to study learning reflect our theoretical understanding. So as theories shift, so must our methodologies.

The field of engineering education research (EER) began with a positivist methodological backbone, likely the result of EER researchers trained in fields such as engineering. Over the past decade, however, EER can be seen as undergoing a paradigm shift [5] from the old methodologies toward qualitative and mixed methods [1]. Many authors argue that there is no universally preferable research method, but that instead the method should be matched to the research question [1]. These new methodologies enable us to ask new questions and produce new kinds of knowledge. Therefore, we might ask what kinds of research questions are important in EER and what methodologies do we need to answer these questions?

One goal of EER is for the research to support advances in engineering education practice - to help support practice-related goals such as deeper learning, better preparation for work, broader inclusion of students, and issues of equity. We wonder what room there is for additional research methodologies to be in EER's methodological repertoire. The addition of interpretivist methodologies in EER allows us to move beyond assessment to create knowledge about experiences and meaning. However, current methodologies only answer questions about *what is*. EER does not yet have methodologies to address research questions about *what might be*. These further thinking questions are the domain of design research methodologies - methodologies that leverage the design process to surface new knowledge.

Against this backdrop, we focus on research through design (RtD), a design research method used in the field of human computer interaction (HCI). In this paper we ask: ***What role might research through design play in the engineering education research field?*** We use a RtD approach to examine what it might look like to use RtD in live teaching situations. Our approach involves the implementation of RtD by two educators through the design and implementation of two undergraduate courses during the winter quarter of 2021.

We seek to introduce RtD to the education community through an example of its use. Thus, this is not a theory paper, nor is it a quantitative or qualitative assessment paper, but instead a design contribution. We begin with a background section introducing the methodology of research through design (RtD). This is followed by two results sections. The first results section presents our design contribution - an account of our methodological design and design rationale for how we applied RtD in our context. The second results section points out key lessons learned from our experience of doing RtD both as educators and researchers. In our discussion, we compare implementations of RtD in HCI with our experience to surface epistemological, methodological, and legitimacy questions around the use and value of RtD in our field.

2. Background

2.1 Design as a Research Method

Research through design (RtD) is a research methodology that borrows the methods of design and the goals of research [2]. In many ways the methods and goals of design and research are quite disparate and in tension. Broadly speaking, the aim of research is generating new knowledge while the aim of design is the creation of an artifact that does not yet exist. A number of research methodologies exist for surfacing knowledge but, these processes are quite 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 [6]. These three kinds of design research are research into design, research for design, and research through design (RTD)

Research into and for design are characterized by the type of knowledge created by the research process [2]. Research into design produces knowledge about the practice of design. Consider, for example, Donald Schon’s ethnographic research on architecture that lead to the concept of “reflection-in-action”[7] or Herb Simon’s work using verbal protocol analysis to understand design process and cognition [8]. Research for design is “research intended to advance the practice of design [2]. This would include research that has implications for design or new design methods. For example, the wealth of research in the field of design 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 about design or to help the doing of design. RtD combines the methodologies of design (i.e. problem scoping, ideation, prototyping) with the goals of research (the production of 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” [2].

Research through design (RtD) comes from the interdisciplinary field of Human Computer Interaction (HCI). It was introduced to this community in the early 2000s and developed from a need to leverage the knowledge generated by interaction designers [9][10][11]. Dunne and Gaver [9] propose 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” [6:362]. 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” [9]. RtD can be seen as a response to the challenge in HCI that “things proceed theory” [2]. A classic example of this in HCI is that the mouse needed to be invented before it could be shown to be a good design. We have a similar challenge in EER - innovative learning environments need to be designed before we can prove them to be good learning environments. RtD has achieved increasing interest and attention in HCI. Recently, use of RtD has even cross-pollinated to other communities [12]. Though RtD has not yet been used in EER.

We refer to RtD as a methodology, rather than a method, because it represents large variety of practices aligned by an “emphasis on the importance of creating design artifacts as a means to uncover new knowledge that could not have been arrived at otherwise” [13]. Zimmerman and Forlizzi suggest several categories of RtD - lab, field, or showroom [2]. Practitioners of RtD describe a variety of methods that extend or fall under the broad umbrella of RtD such as design fictions [14], critical design [2], speculative design [15], research products [13][16], material speculation [13][17], embodied design ideation [15], critical making [15], participatory RtD [12], collaborative futuring [18], and research through explorative design [19].

2. 2 What kind of Knowledge can RtD Produce?

Development and use 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 and there is still much debate, in part due to the fundamental tension between design and research [2]. Stolterman characterizes scientific research as focused on the “existing” and “universal”, while design is in pursuit of the “non-existing” and the “ultimate particular [20].

There are calls for consolidation of practice and definition of rigor in RtD. 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 [10]. RtD produces knowledge referred to as “intermediate level knowledge” [21] a “type of design knowledge that lies between [generalized] theories and design instances” [17:2]. Gaver [10][22] proposed a method of treating annotations as theory called annotated portfolios. In these portfolios, the design issues, decisions, and rationale of are used to annotated visual artifacts of design. These collections of designs, once synthesized, surface design theory.

2. 3 How to Conduct an RtD Inquiry?

Zimmerman and Forlizzi suggest 5 steps for carrying out RtD: 1) Select, 2) Design, 3) Evaluate, 4) Reflect and Disseminate, and 5) Repeat [2]. In HCI, RtD inquiries are conducted by multidisciplinary research teams that typically include interaction designers, ethnographers, and

computer scientists [23]. The full scope of a RtD project, including multiple iterations of design and deployment, is often several years [24].

The selection phase refers to identifying a design research problem or opportunity to pursue. In the HCI literature, many inquiries frame their aims or motivation as “Designing for _____ interaction”. 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” [23]. Ludic engagements are “activities motivated by curiosity, exploration, and reflection rather than externally defined tasks”[23:885]. Other areas of design include design for “slow”[13][25] interactions, “collaborative survival” [15], “touch” [26], and “personal and interpersonal connections”[27].

The center of an RtD inquiry is the design phase, the creation of an artifact or system to surface new knowledge that could not be surfaced through other methods. In the context of HCI, these artifacts take the form of furniture [23][27], jewelry [27], music players [13][25][28], or wearables [15][29]. For example, Dunne and Gaver create pillow that lights up based on electromagnetic radiation in the area [9]. Odom and colleagues created Olly, a music player that allows users to re-experience music they listened to in the past, to explore “slow” interactions [13][23]. During the design phase documentation of the design process, design decisions, and design rationale is collected and analyzed.

The creation of and reflection on the artifact is often accompanied by other data collection and analysis methods. Many authors conduct “field deployments”[15][25][26] following the design phase. One deployment can last anywhere from a few weeks [24] to over a year [25]. For example, Olly – the slow technology music player - was deployed with three users for 15 months in the home [25]. During these deployments, techniques such as interviews, photos, and user reflections are used to surface knowledge about user’s interaction with and experience of the designed artifact. Workshops are also used as a means better understand user interaction with the designed artifacts.

In the dissemination phase, RtD knowledge claims come in the form of sharing the “ultimate particular” that was created. 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 [15][13]. Knowledge contributions often also include tactics for designing for these new kinds of interaction [15].

3. Approach

We feel RtD is a promising methodology for EER, specifically for capturing knowledge created during teaching practice. In this paper we ask: ***What role might research through design play in the engineering education research field?*** We use a RtD approach to examine what it might look like to use RtD in live teaching situations.

Our approach involves the use of RtD by two educators through the design and implementation of two undergraduate courses during the winter quarter of 2021. Over about a 12-week period, design work was carried out individually by each educator and documented. Weekly reflection meetings were used to collaboratively document design artifacts and rationale from each course.

About halfway through the quarter, the emergent question of “pedagogical wayfinding” surfaced and we pivoted, using and annotated portfolio technique to look across instances of designing for pedagogical wayfinding in both courses.

In this RtD inquiry, we are positioning 1) our specific enactment of the RtD methodology and 2) our experience implementing RtD methodology in our live teaching situations as results. In this case our particular methodology and associated rationale provides an “ultimate particular”, demonstrating one example of how RtD might be carried out in EER through live teaching situations. As such, a more detailed description of our enactment of the RtD methodology follows in the next section.

Because we believe that all knowledge comes from somewhere (as suggested by feminist standpoint theory), we think it is important to say a bit about our positions or standpoints in relation to this work. First, we both identify strongly as designer practitioners and designerly educators in that we really enjoy solving design inquiry questions in relation to pedagogy. Second, we are both very much interested in RtD because of our designerly orientations but also because of the desire to know more from other designers. Because we are advocates, though, we have tried to keep this paper balanced in terms of enthusiasm as well as critique.

4. Results: Our Enactment of RtD in Two Live Teaching Situations

In this RtD inquiry, we are positioning our specific enactment of the RtD methodology as a design contribution. In this case our particular methodology and associated rationale provides an “ultimate particular”, demonstrating how RtD might be carried out in EER through live teaching situations.

4.1 Design Problem

RtD begins with a design research problem or opportunity. Both authors were familiar with RtD as a methodology and were interested in how it could be applied to live teaching situations. Both authors were also involved in teaching undergraduate courses in the 10-week winter quarter of 2021. Author 1 was involved in teaching a project based undergraduate studio class on human centered design for 75 students. This was the author's second quarter teaching this course. Author 2 was involved in teaching a seminar course reading and discussing academic works. This was the author's first quarter teaching this course. The first step in our inquiry was to frame these teaching experiences as design opportunities that could surface new knowledge related to our research interests.

After recognizing each teaching engagement as the site of a potential RtD project, we identified design research aims for each. Author 1 is at the tail end of a multi-year RtD project that explores designing learning environments that support design metacognition and asks “how might we design pedagogical experiences inspired by variation theory? After having looked at this question in informal contexts, this particular teaching engagement was a chance to examine the same design inquiry question in a formal teaching context. For the second author, the research question emerged over time as: “how might we create structures that support inclusive, engaging, productive discussion despite the remote setting”. For both authors, our research aims were based on prior practice and theoretical knowledge. However, constructing the formalized questions evolved throughout our process of treating our teaching as RtD.

While these teaching engagements were opportunities for design research, they also brought with them a number of design constraints, problems, and opportunities not necessarily tied to our research aims. For example, both courses were being taught during the global COVID-19 pandemic. As a result, our academic institution had transitioned all classes in our department to remote teaching carried out in the Zoom video conference platform. Both courses had been taught in person prior to the pandemic and both authors had more experience teaching in person. The required shift of both of these courses to online learning was not the direct subject of our research inquiry but it did present design opportunities and challenges that we took into account in our designs. For example, the shift to online learning opened up the opportunity and need for online technologies for sharing work, such as Miro collaborative digital whiteboards or Google slide decks. Asking the same inquiry questions during live teaching experiences would have resulted in different design artifacts.

4.2 Design Solutions + Iterations

In RtD, an artifact is designed and the rationale behind design decisions is used to create new knowledge. In HCI RtD studies, the artifact of design is often an object - a music player, a wearable, or a piece of furniture - that prompts a new form of interaction. For us, we focused on the design of learning environments - in particular the design and iteration of two specific undergraduate courses. At the beginning of our research inquiry, we focused on the course as a design artifact. In our reflection meetings smaller designed artifacts emerged as a focus due to the size and complexity of looking at the entire course as a designed object. For example, one focus of Author 1's inquiry was the design of a digital "design workbook". In both courses we focused on Miro digital whiteboards set up for class activities as smaller designed artifacts that were part of our course design.

Many RtD studies describe teams of designers and researchers creating an artifact then later deploying it in "field studies" with users to gather more information. The timescale of design work and field studies in HCI can range from a few months to over two years. For us, the nature of our design collaboration and implementation was different due to our need to honor the teaching situations we were in. We chose not to design the same artifact, but instead to collaborate by supporting each other in surfacing and articulating our design rationale in reflection sessions. We focused our research on a period of design that unfolded over about 12 weeks due to the nature of our 10-week academic quarter. While we did do a large amount of design work and planning prior to the beginning of the quarter, our designs and deployments were interwoven.

We found ourselves iterating our designs on at least three timescales: across quarters, within the quarter, and in the moment. At the largest timescale, we made design decisions about the implementation of the course that differed from prior instantiations of the course. We were also iterating substructures of the course at an intermediate timescale within the quarter. For example, the "design workbook" mentioned prior was created for each of 10 assignments and author 1 chose to iterate each time based on new knowledge learned in the prior iteration. Finally, we found ourselves making changes in our designs during a class to accommodate new information or shifting circumstances.

4.3 Data Collection + Reflections Analysis

Throughout the process of designing and implementing our coursework, we engaged in documentation of and reflection on our design decisions and rationale. Each author had methods of idiosyncratic documentation of that aligned with our typical practices of teacher-researcher. For example, author 1 took field notes after each weekly lecture. Both authors constructed representations of the work along the way, such as visual representations of how much time was spend on certain activities during a class session.

The design and implementation process itself also yielded design artifacts that could later be examined. For example, digital example traces of our course designs could be found in the Canvas course management system, Miro collaborative digital white board, and Google slide decks.

Over a period of about 12 weeks, both authors met weekly to collaboratively share designs and design rationale. These meetings were structured through the use of a digital white board where we placed representations of our design work to share with each other.

4.4 Emergent Design Research Aim

About halfway through the quarter, we surfaced an emergent design research question that cut across both of our research projects. “How might we support pedagogical wayfinding for students?” We decided to scope our analysis to focus on this shared research aim.

Pedagogical wayfinding refers to the work of a learner to keep track of their position in a pedagogical experience (i.e., an experience orchestrated specifically to bring about learning). Pedagogical wayfinding is clearly not new. Just as we need to wayfind to move about in physical space, students need to wayfind to move about in the pedagogical space. There are times when wayfinding does not draw attention. For example, if we are walking in a familiar setting, we might not need to rely on anything in order to know our way around. Similarly, if a student is in a traditionally orchestrated learning experience, such as textbook chapters, frequent homework problems, and regular tests, the need for pedagogical wayfinding may be minimal. If, however, a student is in a pedagogical experience that is less familiar and/or more complicated, then the need for pedagogical wayfinding may be increased.

The pivot to pedagogical wayfinding emerged as a way forward during one of our reflection sessions. As part of our process, we had been putting visual images representing our pedagogical design work on a shared whiteboard and talking through our work. As part of this, we noticed that we were both spending a lot of effort to help students keep track of where they were in our designed experiences. We shared this initial notion of pedagogical wayfinding with peers and liked the response that we got, and thus decided to use it as the primary example.

4.4 The Annotated Portfolio

We constructed an annotated portfolio to showcase both our design solutions and the knowledge that we gained from them.

The first step in constructing an annotated portfolio is to identify the instances of design to be analyzed and compared. In our work to make sense of pedagogical wayfinding, we identified

three sites of pedagogical wayfinding based on technological platforms, and then investigated the specific wayfinding “solutions” we had offered at each site. These three sites were the Canvas course management system, Google Slide Decks, and Miro digital whiteboard. The number of design artifacts drawn from each site can be seen in Figure 1.




Portfolio Curation: Design Artifacts		HCDE 419	HCDE 210
Canvas Site		1	1
Slide Decks		20	10
Miro Boards		12	10

Figure 1. The design artifacts analyzed in the annotated portfolio include traces of design in two undergraduate courses (HCDE 419 and 210) and across three sites of pedagogical wayfinding (Canvas, Google Slide Decks, and Miro Digital Whiteboards)

The next step in constructing an annotated portfolio is to iteratively collect and arrange (1) representations of our design work (e.g., the slide decks) and (2) annotations of design choices and rationale related to creating pedagogical wayfinding. In Figure 2, we carved off a chunk of our design work related just to one site - Google Slide Decks. On the left side you can see an image of all ten slide decks. On the right you can see iterations of certain kinds of slides over the 10 weeks. The kinds of slides are arranged from top to bottom according to what kind of wayfinding they are providing. Post it notes were used to annotate design choices related to pedagogical wayfinding.

As mentioned, this work is in-progress, but the beginnings of themes can be seen in the colors of the post-its. The orange post-it notes, for example, denote the use of different visual elements to create “you are here signage” for students. The pink post-it notes begin to note instances of using naming conventions to orient students.

In addition to the themes, arrangement of the design representations also surfaced information for us. For example, from left to right you can see levels of hierarchy in wayfinding. From top to bottom you can see attention to wayfinding broadly across the course to more narrowly across one activity in the course. While this is not particularly surprising, the identification and naming of these dimensions leads us to think in the future about how broadly we are orienting our wayfinding. For example, we were drawn to think about what it would look like to be broader. How might we orient our students to broader pedagogical progressions across courses?

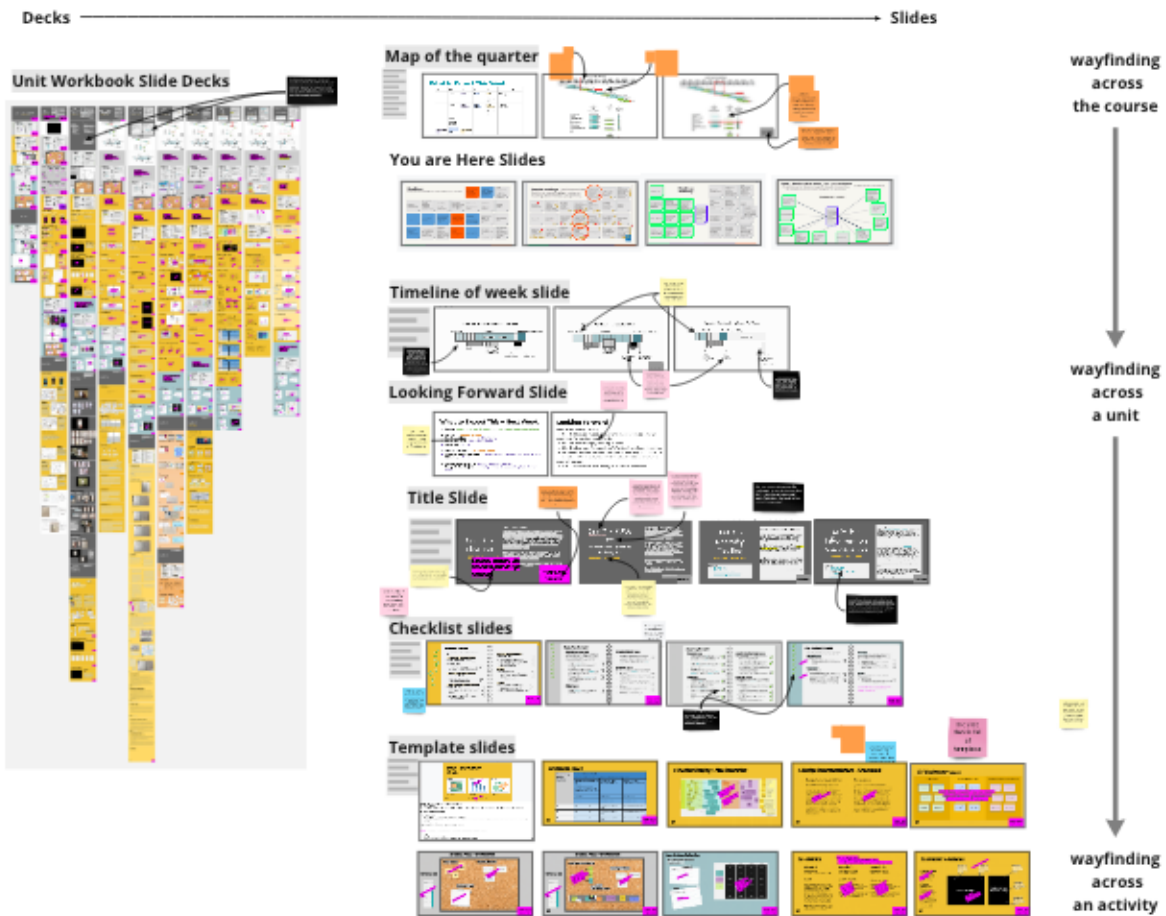


Figure 2. *Annotated Portfolio of design representation from course slide decks.*

5 Results: Our Experience doing RtD in Live Teaching Situations

We chose to implement RtD in live teaching situations in which we were already engaged. Here we point out 4 (of many) lessons learned from our experience enacting RtD in our specific context.

5.1 Seeing Teaching as Design

To apply RtD to EER to live teaching situations, we first had to choose to see what we were doing as design. As educators, we sometimes engage in collaborative large-scale efforts – such as the design of new course or development of a new disciplinary programs – that are easy to see as design. However, teaching is not always design. Educators often engage in teaching experiences that do not involve creating new learning environments to solve problems. For us, it is natural to think of our teaching as design.

In these two particular teaching situations, it was easy to see our work as the design and deployment of learning environments. However, determining exactly what our design research artifact was proved a little more difficult. At times in our reflection sessions, we would find ourselves talking about the outcome of our learning environment as the design. For example, we found ourselves describing “designing discussions” rather than designing an “environment that

supports certain kinds of discussions”. Over the course of our analysis and design we moved from looking at our courses as the design artifact to pulling out smaller pieces to focus on because of the scale of design in our courses. This scoping became more apparent when we narrowed to pedagogical wayfinding as certain artifacts were much more involved in that design problem than others. These experiences open up the methodological questions when applying RtD to EER of what are the design artifacts in an RtD inquiry of teaching practice?

5.2 Tacit and Emergent Design Problems

Zimmerman and Forlizzi suggest that RtD begins with a design problem or opportunity. Though we began with design research aims, we found that throughout our process 1) tacit design problems surfaced through our reflection on design solutions, 2) we were simultaneously dealing with many design problems or opportunities, and 3) our original research aims clarified and new aims emerged.

By tacit design problems we mean things we were designing for before being able to really articulate them as our design aims. For example, it was only through explaining the rationale behind the ‘design workbook’ that Author 1 realized she was designing elements of the course to support and hold students accountable for their design process as well as the design products.

Many of the somewhat tacit design opportunities and problems we were designing for were related to our practice situations, not necessarily our design research aims. For example, prior we mentioned the shift of in person learning experiences to online learning experiences due to the COVID-19 pandemic. We also had a number of design constraints, such as the length of the quarter and number of students enrolled in our courses, imposed by our live teaching situations not our research questions. We noticed that in live teaching situations we do not have the luxury of designing just for the sake of new knowledge, we must also have a design artifact that serves the purposes of teaching.

As mentioned in the prior section, “pedagogical wayfinding” emerged as a potential design research aim that both authors were both designing for in our separate teaching engagements. The pivot to pedagogical wayfinding emerged during one of our reflection sessions. It was always something we had been designing for, but it was not our originally named RtD question. These experiences with the design research problem suggestion open questions about how we might consider emergent design research problems in RtD.

5.3 Wearing Multiple Hats

In our experience conducting this RtD inquiry, we found ourselves to be wearing multiple “hats” – taking on the roles of researcher, designer, and educator – throughout the process. RtD literature discusses the extra constraints research puts on design – such as rigorous documentation of what is often a messy process – in order to surface accountable knowledge. We see this as requiring the designer-researcher to shift between their researcher and designer stance (hats) throughout the inquiry process. In our inquiry, we had the addition of the educator hat.

At times these different roles complemented each other. We found it exciting and rewarding to move very clearly between the designer-practitioner space and the researcher space. We put our energy into our teaching, and then turned through our engagements with each other, to stepping

out of the work to identify the lessons. In putting on our researcher hat, we were able to identify “pedagogical wayfinding”, something we had been doing all along but had not named or made explicit. After naming it, when we put back on our design or educator hat, we could see this concept put to use in practice.

While we found the switching between the hats to be productive, the designing for both practice and research came with constraints. RtD is described as turning the practices of design toward the goal of surfacing knowledge. In HCI, there are RtD studies that explore “counterfactual artifacts” – artifacts that look like fully realized products but have weak purpose or whose use in context may contradict with what would normally be considered logical [13] Olly – the slow interaction music player described earlier – is described as a counterfactual artifact. In the case of Olly, the music player plays songs at random rather than giving the user control. This contradicts with users’ typical interaction expectations and causes an initial frustration. Because we were designing in live teaching situations, we did not feel we had the luxury of creating “counterfactual artifacts” or an artifact just for the sake of surfacing knowledge. Our designs needed to also be functional in teaching practice. This experience calls us to step out and ask what balance is required in EER to surface knowledge from design while still honoring the teaching and learning goals of the designed artifact.

5.4 Data Collection + Reflection

In truth, because our teaching demands were quite extensive, it was very difficult to keep formal notes of a particular kind. That said, two features of our situation helped offset such a challenge. First, because we were operating in the remote environment where almost all activity was digitally mediated, we had our digital traces to serve as a foundation for our memories and our analysis. Second, we leveraged each other. When we came together to share our practice, we could offer a kind of support for each other that moved the work along. For example, we asked each other questions about rationale, and we noticed elements of practice as potentially significant. We think this points to the particular potential benefit of collaborative research through design.

6. Discussion

In this discussion, we offer a takeaway for each of our previous two results sections. In the first section below, we connect to our focus on pedagogical wayfinding from the first result section. In the second section below, we connect to our experiences of engaging RtD (as discussed in the second results section).

6.1 Designing for ____ Learning:

In HCI, many RtD works frame their aims or motivation (design problem) as “Designing for ____ interaction”. Using the future orientation of design, they imagine new modes of interaction between humans, their environments, and technology - modes of interaction that push beyond utilitarian design to address larger societal problems. For example, designing for “collaborative survival (multi-species interactions)”, “lucid” interactions, or “slow” interactions.

In our experience we found the emergent aim of **designing for “pedagogical wayfinding.”** In naming this aim, we can imagine this as a specific kind of learning experience that educators

might want to design for. We then can also imagine how the community might benefit from tactics for designing for “pedagogical wayfinding” in learning experiences.

Stepping back, we might ponder what other aims might RtD open up for EER? How might we fill in the blank of “Designing for _____ learning”? What kinds of learning experiences do we currently have and what might we turn to as being innovative or addressing larger systemic problems or societal calls? If we consider that much of what we have is designed for utilitarian learning, what might it look like to design for “ludic learning” or “slow” learning? If we are already designing environments for things like “collaborative”, “inclusive”, or “reflective” learning, how might RtD help legitimize and share the knowledge being captured in these efforts?

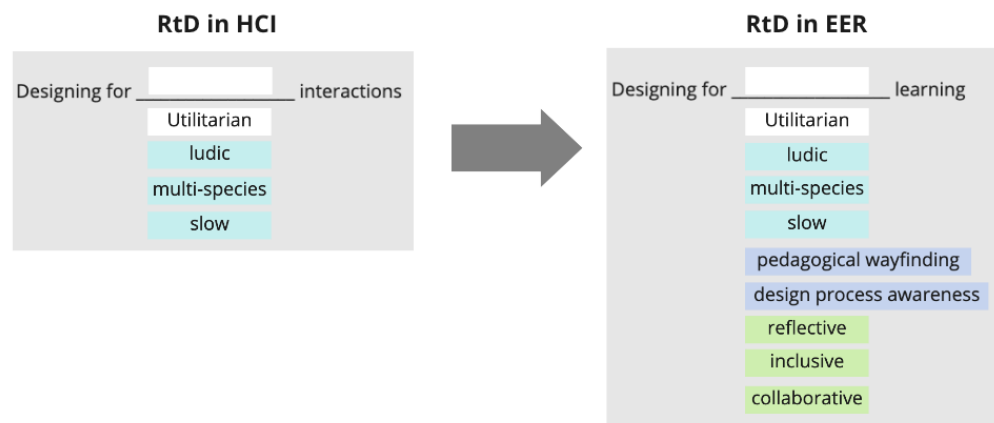


Figure 3. *Visual representation of some design research aims being explored through RtD in the field of HCI and what aims we might consider for EER.*

6.2 Retrospective RtD and the Tacit Problem Space

In implementing RtD in our two live teaching engagements, we enacted our RtD work in a way that was somewhat retrospective. In design process models as well as the 5 step model of RtD described by Zimmerman and Forlizzi, the first step is to select or identify the design problem (problem definition) before proceeding to a solution. However, we found that our design research problems were somewhat tacit and emerged through the reflective work of collaboratively analyzing our design implementations and rationale for those designs.

While this phenomenon seems in opposition to some descriptions of the RtD methodology and design process, we draw on the concept of co-evolution of problem and solution to show that this may be an expected and natural result of employing the design process as research method. Design methods research has proposed that throughout the design process there is movement between the problem and solution space. While the problem is somewhat framed at the beginning of the design process, designers come to better understand and scope the problem over time through the implementation or exploration of solutions.

In our experience, we surfaced the design opportunity (problem) of “pedagogical wayfinding”. We were both tacitly designing for this in our separate teaching engagements, but not necessarily conscious of it as a scoped design problem. In giving it a name, we found it to be a concept we could see more easily and image more consciously designing for in the future. In our reflective

sessions together, being asked to describe the design rationale for changes in the course materials (move from canvas descriptions to digital design workbooks) revealed other design problems of designing for “design process awareness” (we are asking the students to engage in a process, we think process is important, but we don’t scaffold, make visible, or grade the process - we focus on the artifact) We found that treating our work as RtD helped us evolve and see the problem space which helped evolve the solution space.

We wonder what the methodological, epistemological, and legitimacy considerations might be of retrospective RtD for live teaching situations in EER. If many educators are engaged in the design of learning environments through live teaching experiences rather than longer planned design efforts, it would be productive to the community to leverage learning from these experiences. We offer a few open questions that the community might consider. What kinds of documentation might need to be captured along the way in order to systematically consider the rationale of our design choices? How might we make reflection and analysis feasible?

Conclusion

We are hopeful that our contribution has illustrated the potential of exploring RtD for engineering education and has illustrated some of the contours of what such an exploration could continue to address. At a high level, though, we think there are two particularly interesting things for engineering education research to think about. First is the question about the role of design in engineering education practice. We acknowledged in our approach that we situate ourselves firmly in the design camp, but we are just two people. We think that the engineering education community should debate the role of design in practice and that the results of such a debate will help to clarify the potential role for RtD. Second, we wonder about how the engineering education community understands the nature of the design problems in engineering education. In particular, do we think we know what the design problems are and simply need to address what designers before us have discovered? Have we finished finding the design problems or are we just starting? In the field of HCI, those grappling with this question note that since our world is socially constructed, and that designers contribute technologies that change the socially constructed nature of the world, then the design problems never go away. There are always new design problems emerging. We ascribe to this latter view and believe that we are only just starting to see the kinds of design problems that we need to address in order to advance engineering education. If this view is indeed the case, RtD will be a powerful addition to the repertoire of research approaches for engineering education research.

Bibliography

- [1] M. Borrego, E. P. Douglas, and C. T. Amelink, “Quantitative, qualitative, and mixed research methods in engineering education,” *J. Eng. Educ.*, vol. 98, no. 1, pp. 53–66, 2009.
- [2] J. Zimmerman and J. Forlizzi, “Research Through Design in HCI,” in *Ways of Knowing in HCI*, New York, NY: Springer New York, 2014, pp. 167–189.
- [3] J. Zimmerman, J. Forlizzi, and S. Evenson, “Research through design as a method for interaction design research in HCI,” p. 493, 2007.
- [4] A. L. Brown, “Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings,” *J. Learn. Sci.*, vol. 2, no. 2, pp. 141–178, 1992.

- [5] T. Kuhn, *The Structure of Scientific Revolutions*. 1962.
- [6] Christopher Frayling, "Research in Art and Design," *Royal College of Art Research Papers*, vol. 1, no. 1993. pp. 1–5, 1AD.
- [7] D. Schön, *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. Jossey-Bass, 1987.
- [8] H. A. Simon, *The Sciences of the Artificial*, Third edit. Cambridge, Massachusetts: The MIT Press, 1996.
- [9] A. Dunne and W. W. Gaver, "The pillow: Artist-designers in the digital age," *Conf. Hum. Factors Comput. Syst. - Proc.*, vol. 22-27-Marc, no. March, pp. 361–362, 1997.
- [10] W. Gaver, "What should we expect from research through design?," *Proc. 2012 ACM Annu. Conf. Hum. Factors Comput. Syst. - CHI '12*, p. 937, 2012.
- [11] J. Zimmerman, S. Evenson, and J. Forlizzi, "Discovering and Extracting Knowledge in the Design Project," *Human-Computer Interact. Inst.*, vol. 04, no. November, p. 233, 2005.
- [12] D. Wilde and F. A. Bertran, "Participatory research through gastronomy design: A designerly move towards more playful gastronomy," *Int. J. Food Des.*, vol. 4, no. 1, pp. 3–37, 2019.
- [13] W. Odom *et al.*, "Attending to Slowness and Temporality with Olly and Slow Game," pp. 1–13, 2018.
- [14] I. Maldini and P. J. Stappers, "The wardrobe as a system: Exploring clothing consumption through design fiction," *J. Des. Res.*, vol. 17, no. 1, pp. 3–25, 2019.
- [15] J. Liu, D. Byrne, and L. Devendorf, "Design for collaborative survival: An inquiry into human-fungi relationships," *Conf. Hum. Factors Comput. Syst. - Proc.*, vol. 2018-April, pp. 1–13, 2018.
- [16] W. Odom, R. Wakkary, Y. K. Lim, A. Desjardins, B. Hengeveld, and R. Banks, "From research prototype to research product," *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 2549–2561, 2016.
- [17] S. Hauser, D. Oogjes, R. Wakkary, and P. P. Verbeek, "An annotated portfolio on doing postphenomenology through research products," *DIS 2018 - Proc. 2018 Des. Interact. Syst. Conf.*, pp. 459–472, 2018.
- [18] S. Hyysalo, C. Kohtala, P. Helminen, S. Mäkinen, V. Miettinen, and L. Muurinen, "Collaborative futuring with and by makers," *CoDesign*, vol. 10, pp. 209–228, 2014.
- [19] M. Hoby, N. Padfield, and J. Löwgren, "Designing social play through interpersonal touch: An annotated portfolio," *Nord. 2013*, pp. 1–4, 2013.
- [20] Erik Stolterman, "The Nature of Design Practice and Implications for Interaction Design Research," *Int. J. Des.*, vol. 2, no. 1, pp. 55–65, 2008.
- [21] J. Löwgren, "Annotated portfolios and other forms of intermediate-level knowledge," *Interactions*, vol. 20, no. 1, pp. 30–34, 2013.
- [22] W. Gaver, "Making spaces: how design workbooks work," *Proc. SIGCHI Conf. Hum. Comput. Interact.*, pp. 1551–1560, 2011.
- [23] W. W. Gaver *et al.*, "The Drift Table: Designing for ludic engagement," *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 885–900, 2004.
- [24] S. Hauser *et al.*, "Deployments of the table-non-table: A reflection on the relation between theory and things in the practice of Design research," *Conf. Hum. Factors Comput. Syst. - Proc.*, vol. 2018-April, 2018.
- [25] W. Odom *et al.*, "Investigating slowness as a frame to design longer-term experiences with personal data: A field study of olly," *Conf. Hum. Factors Comput. Syst. - Proc.*, pp.

- 1–16, 2019.
- [26] N. Campo Woytuk, M. L. J. Søndergaard, M. Ciolfi Felice, and M. Balaam, “Touching and Being in Touch with the Menstruating Body,” *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 1–14, 2020.
 - [27] V. J. Carpenter and D. Overholt, “Designing for interpersonal connections in future technologies: An annotated portfolio of jewelry devices,” *Proc. Nord. Des. Era Digit. Nord. 2018*, 2018.
 - [28] W. Odom and T. Duel, “On the design of OLO radio: Investigating metadata as a design material,” *Conf. Hum. Factors Comput. Syst. - Proc.*, vol. 2018-April, pp. 1–9, 2018.
 - [29] H. R. Biggs and A. Desjardins, “High Water Pants: Designing Embodied Environmental Speculation,” *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 1–13, 2020.