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ABSTRACT

Humanity has entered an era where computing technology is virtually ubiquitous. From websites and mobile devices to computers embedded in appliances on our kitchen counters and automobiles parked in our driveways, information and communication technologies (ICTs) and IT artifacts are fundamentally changing the ways we interact with our world. Indeed, the world itself changing, becoming ever more artificial. It is a designed world that we have created for ourselves.

Human-computer interaction (HCI) scholars are concerned with the interactions that occur between people and technology in this new world: how do IT artifacts impact the human experience, and how can knowledge of the human experience impact the design of new computer-based systems? At the same time, HCI is design-oriented, a community where scholars seek to shape the design of new IT artifacts, and make real improvements to the world we live in. It remains an unresolved challenge to bring these scholarly and design perspectives together. Various models and approaches have been proposed, but current thinking on a "design science" for HCI is in flux.

This multi-paper dissertation draws upon existing literature from HCI, various design communities, and information systems (IS) to develop a new model of design science: the theory, design, and evaluation (TDE) model. The TDE model, informed by an included research paper, envisions that scholarly activities and design activities can occur in parallel across the three stages of theory, design, and evaluation.

The TDE model is demonstrated using an additional three included papers, each one taken from a separate TDE design science project. These ongoing projects occur in widely varied contexts – gaming for citizen science, online nuisances, and military history education – but each has the TDE model as its central organizing structure. The papers are examples of TDE knowledge outcomes, but also address design outcomes from each project. The three projects are analyzed and connected directly to various elements of the TDE model itself. In addition, the final chapter describes future directions for the three projects and the TDE model, as well as thinking on the importance of design science in HCI scholarship.

DESIGN SCIENCE IN HUMAN-COMPUTER INTERACTION
A MODEL AND THREE EXAMPLES

by

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Syracuse University
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CHAPTER 1: Problem Statement

1. Introduction

Humanity has entered an era where computing technology is virtually ubiquitous. From websites and mobile devices to embedded computers in our kitchen appliances and automobiles, information and communication technologies (ICTs) are fundamentally changing the ways we interact with our world. Information technology (IT) systems such as websites, mobile devices, games, visualizations, and personal computers deeply impact our daily lives and may have even greater impacts in the future – at home, at work, on the road, or virtually anywhere. In short, the technological environment that we live in has become, as Simon (1996) argues, "a much more man-made, or artificial, world than it is a natural world. Almost every element in our environment shows evidence of human artifice."

The IT artifacts that pervade our surroundings are of great interest to many scholars, especially those in the human-computer interaction (HCI) community. Drawing upon a variety of disciplinary perspectives, including psychology, social psychology, sociology, management, organizational studies, computer science, information technology, software engineering, design, and the creative arts, HCI scholars explore how humans interact with information, technologies, and tasks in a host of contexts (P. Zhang et al., 2002). This variety of influences on HCI is in part the result of the discipline's unique scholarly positioning. HCI researchers have two core interests: 1) to scientifically understand human beings, their goals, desires, motivations, cognitions, emotions, and behaviors, and 2) to scientifically understand the artificial world of computer technologies, IT artifacts, ICTs, and information systems. In HCI, these interests are rarely addressed in isolation. Rather, as the name of the discipline implies, HCI scholars are deeply interested in interactions between people and technology: how do IT artifacts impact the human experience, and how can knowledge of the human experience impact the design of new computer-based systems? Knowledge generated over a long history of scholarship in many different fields and disciplines is useful to HCI scholars who study interactions between IT artifacts and the people who use them.

The dual focus of the HCI discipline – the artificial as represented by IT artifacts, and the natural, as represented by human beings – presents unique challenges that are not necessarily confronted by other researchers in other domains. In HCI, there is a base assumption 1) that a given IT artifact will have certain impacts on its human users, and 2) that by understanding these impacts, as well as other human goals, desires, needs, and abilities, HCI scholars can better know how to develop new IT artifacts and improve old ones. These assumptions mean that notions of HCI scholarship typically come loaded with the concepts of iteration and design: when a human phenomenon seems well understood, that understanding should work its way into the design of an IT artifact. Artifacts must eventually be evaluated for their impact on human users, which in turn will generate new knowledge to be integrated into new designs. Carroll (1997) describes this as follows: "Human activities motivate the creation of new tools, but these in turn alter activities, which in time motivates further tools."

The iterative, design-oriented outlook of many HCI scholars implies that a harmonious balance exists between scientific knowledge generation for the human aspects of a problem (i.e. natural or social-psychological science) and design activity for its artificial, artifactual elements. Yet scientific knowledge is not the same thing as design knowledge, and it remains unclear how well these two perspectives complement each other, if at all. The goal of the natural scientist, according to Simon (1996), is, “to make the wonderful commonplace: to show that complexity, correctly viewed, is only a mask for simplicity.” More pragmatically, to March and Smith (1995), natural science, “includes traditional research in physical, biological, social, and behavioral domains. Such research is aimed at understanding reality.” The natural scientist must interrogate and explicate naturally occurring phenomenon. Our understanding of how to do this has progressed over time, from strictly descriptive science in the days of Copernicus, Kepler and Tycho Brahe to the past several hundred years of theoretically-oriented science to recent advances in computational simulations and finally toward a future (sometimes referred to as the “fourth paradigm” of science) of large scale data exploration that embraces empiricism, theory, and simulation equally (Gray, 2009).

These views of science, emphasizing description, empiricism, and theory, stand in marked contrast to views of design. According to Lawson (2004, 2005; Lawson & Dorst, 2009) and Zimmerman, Forlizzi, and Evenson (2007), designers have the goal of transforming the world from its current state to one that is preferred. To Fallman (2003), “Design is a matter of making; it is an attitude to research that involves the researcher in creating and giving form to something not previously there. This process of making calls for a certain level of ‘involvement,’ which metaphorically resembles the way carpenters must be directly involved with the materials of carpentry; its physical tools, techniques, and materials,” (Fallman, 2003). The designer is interested in action – the improvement of a certain set of circumstances through design. New design knowledge can originate from precedent and example, as past designs and design activities are creatively applied to new contexts, users, and problems (Boling, 2010; Lawson, 2004, 2005; Lawson & Dorst, 2009; Smith, 2010).

Thus, the two worlds – design and science – seem separate: scientists endeavor to understand the existing world as it is, while designers look for problems to solve and improvements to make. Despite this, HCI, considered a science, is also steeped in design because of its strong connection to artificially produced IT artifacts (Benbasat, 2010; Browne, 2006; Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992, 2006; Carroll, Singley, & Rosson, 1992; Dillon, 2009; Fallman, 2003; Mackay & Fayard, 1997; Norman, 2002; Norman & Draper, 1986; Shackel, 1984, 1997; Zimmerman et al., 2007).

For HCI scholars, this mix of designer and scholar perspectives raises uncomfortable dilemmas: can knowledge gained through design carry the same weight of validity and reliability as scientifically gained knowledge? If not, should design activities be relegated to HCI practice? If this were to occur, how relevant to the human world of artificial artifacts would scholarly findings be? If design activities continue to be embraced in HCI scholarship, will emphasis on action, precedent, and the creative act undermine impartial, scientific knowledge generation? Finally: Is it possible to partner scholarly and design perspectives in order to generate knowledge that is equally compelling for both scientists and designers? If so how?

2. Focus of the Research

This dissertation study adopts the perspective that design activity in HCI, while it may exist in tension with scholarly activities, can be a valuable asset for HCI scholars and should be embraced. At the same time, it acknowledges that HCI scholarship is not the same thing as HCI practice. Design processes, if they are to be of value to the HCI researcher, must be carefully partnered with scientific processes in a way that makes them an integral part of the process of inquiry. Currently, this is not often done within the HCI community. While exceptions exist, many design-focused HCI studies tend to exclude theoretical or evaluative aspects that help to elevate design to a mode of inquiry. All too commonly, the HCI community produces what Ellis and Dix (2006) refer to as, "I did this, and it's cool" studies. On the other hand, the fracturing of the HCI community into disparate "camps" with many varying interests (Grudin, 2005, 2006; Ping Zhang & Dillon, 2003) has resulted in some communities where design is considered atheoretical or unscientific, and so virtually eliminated as a meaningful avenue for knowledge generation.

In response to these challenges, this dissertation study presents the theory, design, and evaluation (TDE) model of design science inquiry. This model incorporates both scientific and designer perspectives, and shows a possible approach to partnering design activity with scholarly activity for the ultimate benefit of designers, scholars, and end users. The TDE model is developed out of thinking on design science that exists in the HCI and information systems (IS) communities, where design science is viewed as an approach to scientific inquiry through which research questions are addressed by designing and evaluating IT artifacts (Hevner, 2007; Hevner, March, Park, & Ram, 2004; March & Smith, 1995; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). In this dissertation, design science is explored through two lenses: 1) as a *stance on inquiry*, which unifies designer and researcher perspectives, and 2) as a *process of inquiry*, with guidelines for how to meaningfully conduct research while simultaneously and complementarily developing and evaluating an IT artifact. The following thematic research question is of central concern:

> **Thematic RQ:** How can the scholarly perspective and the designer perspective complement each other in a unified process of inquiry to produce and disseminate useful knowledge to HCI scholars, designers, and end users?

There are a number of different views of design, ranging from very “conservative” structured approaches that treat design as a virtually scientific activity to “pragmatic” perspectives where design is highly situated in context to “romantic” visions of designers as creative and unknowable geniuses (Fallman, 2003). Lawson (2004, 2005; Lawson & Dorst, 2009) describes a view of design based upon empirical evaluation of real-world designers, where design is defined as an expert activity informed by accumulated reservoirs of knowledge: design techniques and familiarity with prior precedent. Every vision of design science necessarily adopts one of these perspectives on design, but it is rare for design science writers to explicitly acknowledge which view they are informed by. The more conservative views are most common, but it is not clear that this vision of design is the only useful perspective for supporting design science activities. Accordingly, the following subsidiary research questions on design are addressed in this dissertation:

> **RQ1:** What are the prevailing views of design adopted by various design science perspectives, and what impact do these have on different existing models of design science?
>
> **RQ2:** How do different views of design shape possible responses to the central, thematic research question?

Delineating how scientific and designer perspectives can combine into a unified research effort may be of great value to the HCI community. However, these different perspectives also make design science an approach to inquiry that can be fraught with tension – tradeoffs, complications, and challenges that result from competing scientific and practical goals. For example, one possible source of tension is when the design problem to be addressed competes with research goals for attention, rather than complementing them. A second source might be design solutions that are too technologically complex to be feasible, and a third could be when theoretical assumptions match poorly with design realities, producing useful scientific knowledge but poorly functioning IT artifacts. The overall feasibility of design science projects, which can become more time consuming and assume a greater scope than expected, is also a perennial concern. The potential risks of design science motivate the following subsidiary research questions:

> **RQ3:** What tensions result when directing different designer and researcher perspectives toward the common goal of knowledge generation?
>
> **RQ4:** How can the designer-researcher manage these tensions?

The concept of a "wicked" problem is frequently raised in the design science literature. These are difficult problems that defy easy or obvious answers (Brooks, 1987, 1996; Rittel & Webber, 1984). According to Hevner et al. (2004), such problems are typically characterized by: 1) "Unstable requirements and constraints based upon ill-defined environmental contexts, 2) complex interactions among subcomponents of the problem and its solution, 3) inherent flexibility to change design processes as well as design artifacts (i.e., malleable processes and artifacts), 4) a critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions, and 5) a critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions," (Hevner et al., 2004). It is frequently argued that design science is a science of grappling with such problems, but because they are inherently unstable, wicked problems put any theory of design science in a constant state of scientific revolution (Hevner et al., 2004; Simon, 1996).

In this dissertation study, wicked problems are not the solitary point or singular focus of a model of design-oriented inquiry. This is a departure from existing design science literature, which tends to downplay the role that "non-wicked" design tasks can play in service to a natural science mindset. In general, the existing design science literature implicitly suggests that a design problem won't really support design as science unless it is "wicked." However, developing or repurposing an existing technology for use in a new context can help the natural or social scientist to understand a great many things about that IT artifact, as well as the context(s) in which it has and will be deployed. To do this is not necessarily an extraordinarily challenging design problem, but it still requires both designer and researcher mindsets, and it is still a way of leveraging design activity and the resulting IT artifact for inquiry. In the TDE model of design science, design activities need not specifically address wicked design problems, so long as they do enable knowledge generation that is valuable to both designer and scholar. Accordingly, this dissertation addresses a final subsidiary research question, specifically on the kinds of design and research problems that a designer-researcher might be interested in:

> **RQ5:** What are some examples of HCI research questions, contexts, problems, and technologies that are of interest to the designer-researcher who adopts design science as a mode of inquiry?

3. Multiple Paper Format

This dissertation adopts a multiple paper format, in which four of the author's previously written scholarly papers comprise the main body of the text. The first of these papers is selected because of the way it conceptualizes three key aspects of design science (theory, design, and evaluation) and examines them in the context of the HCI discipline. This paper is used as a springboard for discussion of the TDE model, and the three aspects form the model's core stages. The three remaining papers describe three separate HCI design science projects carried out under the aegis of the TDE model. These projects address the topics of purposeful gaming to support citizen science, online nuisance coping, and information visualization for military history education respectively. Each paper is an example of the kind of knowledge outcome that can come from design science and demonstrates the use of the TDE model on a real design science project.

Paper one is *Theory, Design and Evaluation – (Don't Just) Pick any Two* (Prestopnik, 2010). This paper proposes three iterative stages of design science: theory, design, and evaluation. These stages are similar to design science cycles (relevance, design, and rigor) proposed by Hevner (2007); however, in Prestopnik (2010), the three stages are tied more closely to the perspectives of the scholars who deploy them, with an argument that scholars from different backgrounds and traditions tend to emphasize different stages because of their unique points of view. Ultimately, *Theory, Design and Evaluation – (Don't Just) Pick any Two* contends that in HCI scholarship generally, and design science in particular, all three stages should be treated with equal merit. Equivalent attention to theory, design, and evaluation will generate disciplinary and scholarly benefits for the HCI community, including greater cooperation between the several distinct "camps" of HCI. The theory, design, and evaluation stages form the core of the TDE design science model proposed in this research study.

Paper two is *Purposeful Gaming & Socio-Computational Systems: a Citizen Science Design Case* (Prestopnik & Crowston, 2012). It addresses all three theory, design, and evaluation stages. The paper describes an ongoing project exploring motivation and gaming within the citizen science context. Citizen science is a crowdsourced approach to collecting and analyzing scientific data (Cohn, 2008; Wiggins & Crowston, 2011). While some sciences are generally perceived as charismatic and interesting (e.g. astronomy, bird watching), other important scientific projects may attract many fewer participants (e.g. classifying molds, lichens, moths, etc.). A critical research area in the citizen science domain is exploring participant motivation and finding ways to engage participants in science that is not inherently charismatic to most members of the general public. One potential way to do this is through purposeful games, which can be fun and interesting to players, but also engage them in real science activity. In *Purposeful Gaming & Socio-Computational Systems: a Citizen Science Design Case*, the research design, system design, and some theoretical underpinnings of a large-scale design science project are discussed.

Paper three, *Online Nuisances and Annoyance Coping: Empirical Investigations and a Theoretical Model* authored by Nathan Prestopnik and Ping Zhang, is an example of one possible beginning for design science scholarship: scholarly interest in theory and evaluation which can lead to design activity. Written as a traditional HCI social-psychological research paper, this study represents the kinds of natural science inquiry that make up the bulk of the scientific literature across many fields and disciplines. It presents a model (Coping with Online Nuisance Encounters: CONE) for how individuals cope with nuisances on the web. The CONE model is grounded in two psychological theories and developed out of empirical data. *Online Nuisances and Annoyance Coping: Empirical Investigations and a Theoretical Model* is included for its theory and evaluation emphasis, and also because it points the way toward future design activity around online nuisances. A number of practical findings from this study are well positioned to motivate the development of web-based systems that capture user attention while avoiding key sources of online annoyance.

The fourth and final paper is *Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO)* (Prestopnik & Foley, 2012). This paper emphasizes theory and design, and is developed out of prior TDE design science work (Prestopnik & Foley, 2011) in which a visualization system (TEMPO: The Temporally Enabled Map for Presentation) was conceptualized, designed, developed, and evaluated for use in the military history classroom. The TEMPO project successfully combined researcher and designer perspectives to address a key design problem in military history education (the static nature of typical paper maps, which do a poor job of relating temporal information to the viewer) as well as to study how visualization tools can impact the classroom lecture experience for students and instructors. In *Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO)*, the TEMPO project is evaluated in terms of its design activity. The occasionally conflicting, occasionally complementary perspectives of the designer and researcher are an important aspect of this work, and many practical lessons about incorporating design into the process of inquiry are discussed.

The conceptual paper (paper 1) and three demonstration papers (papers 2-4) are framed by additional chapters and a concluding discussion. In chapter two, a review of the literature explores designer vs. scholarly perspectives and expresses various views of design science from several fields, especially HCI and IS. Following the literature review, the paper *Theory, Design and Evaluation – (Don't Just) Pick any Two* (Prestopnik, 2010) is presented in full. It is followed by chapter four, a conceptual chapter where the TDE model of design science is presented and described in detail. A brief methods chapter describes how the three example papers will be used to demonstrate the TDE model for design science. To conclude the dissertation, the three demonstration papers are presented in full, and a final discussion chapter builds upon the selected demonstration papers by exploring them 1) as they relate to the central and subsidiary research questions of the dissertation study and 2) as they relate to the various elements of the TDE model of design science. Specifically addressing RQ5, the concluding chapter examines future directions for each of the three example projects and for design science scholarship around the TDE model.

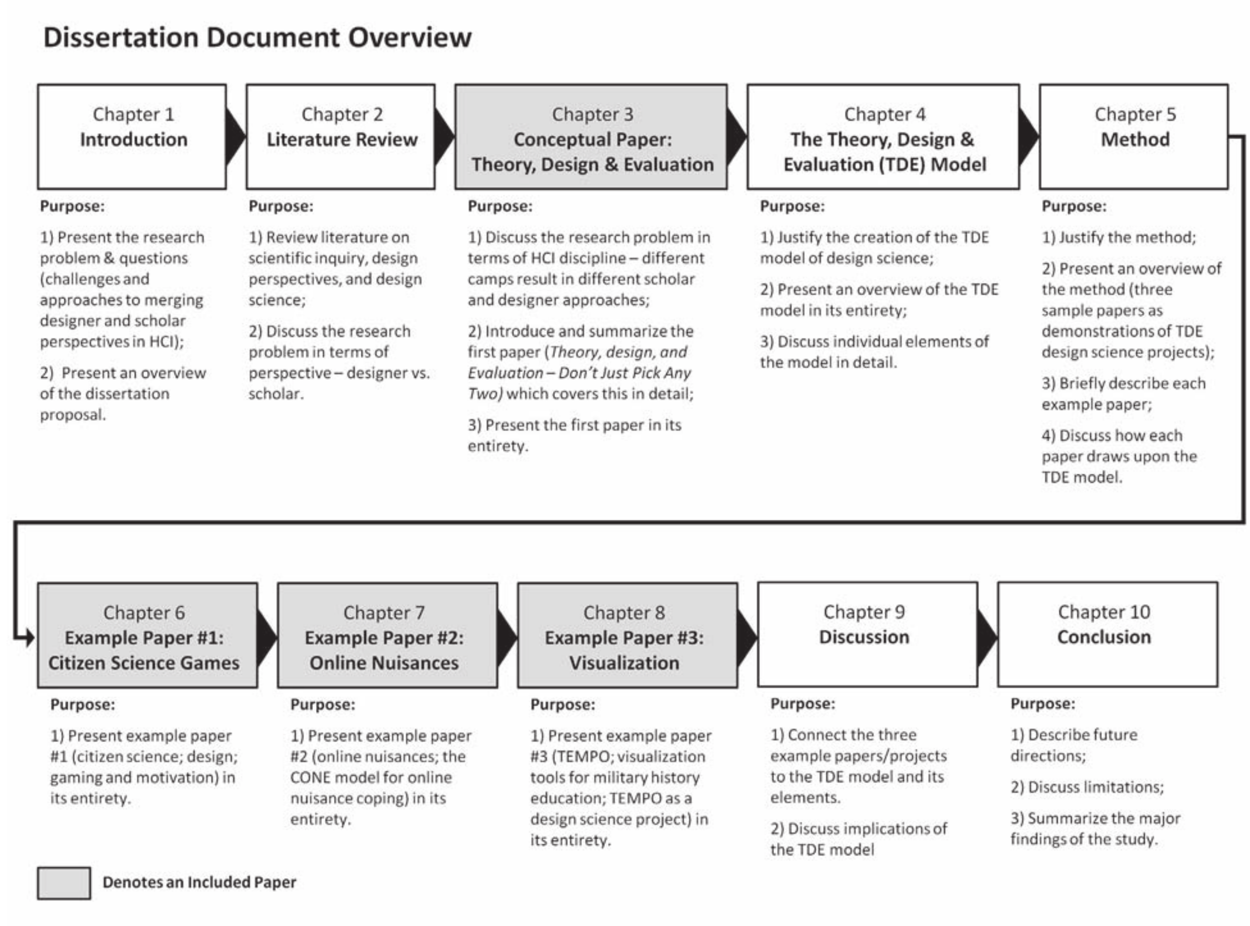

Figure 1.1. Document overview, showing the chapter progression and the four included papers.

4. Why Design Science Matters

HCI is a discipline steeped in design and scholarly activities, but in its present state, these activities don't always complement each other very well (Forlizzi, Zimmerman, & Evenson, 2008; Lawson, 2005; Peffers et al., 2007). Some in the HCI community are designers, but fail to connect their design processes to broader scientific questions. Others are scholars, but their work can be distant from real-world design and development activities. Despite a lengthy history of thinking on design science activities within and outside of HCI, there still remains little consensus on how design and science can be productively joined. In addition, there are many different perspectives on what it is to do design, all of which impact our understanding of design science (Fallman, 2003).

Nonetheless, we live in an artificial world made up of artifacts and technologies designed by human-beings. To study such a world, new and flexible modes of inquiry are necessary. Design science is a promising approach that makes it possible to scientifically study the human experience as it relates to IT artifacts while simultaneously creating new and powerful interactive experiences. It is a tool for blending meaningful research questions with challenging design problems. Finally, it is a holistic perspective that allows HCI scholars to study human beings, evaluate the interactions that occur between people and IT artifacts, and engage with design processes that can change the world. To think formally about design science is to think formally about the very nature of scholarship in HCI.

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CHAPTER 2: Review of the Literature

1. Introduction

Human-computer interaction (HCI) has long been considered a design-oriented discipline (Benbasat, 2010; Browne, 2006; Carroll, 1997; e.g. Carroll & Campbell, 1989; Carroll & Rosson, 2006; Dillon, 2009; Hevner & Zhang, 2011; Norman & Draper, 1986; Shackel, 1984, 1997; P. Zhang & Galletta, 2006a, 2006b), even back to its earliest roots in ergonomics during the first and second world wars (Shackel, 1997). Today, HCI is steeped in design thinking. The notion of user centered design, an approach to design activity that draws upon psychology and user input to make more usable artifacts (Abras, Maloney-Krichmar, & Preece, 2006; Carroll & Rosson, 2006; Norman, 2002; Norman & Draper, 1986; Shneiderman, 1998), has become so widely accepted that it has entered the mainstream consciousness and has influenced design thinking the world over (Vredenburg, Mao, Smith, & Carey, 2002). Other design approaches, like activity centered design (Gay & Hembrooke, 2004; Norman, 2005, 2006), are more controversial but nonetheless highly interesting to the HCI design community. Furthermore, there are many sub-disciplines of HCI that specialize in the design and development of prototype tools and technologies; these are HCI scholars who actually undertake to do design using the methods and approaches suggested by others.

Design is simultaneously but disharmoniously viewed in various ways by various thinkers: as an engineering-oriented process, a mysterious "black box" art form, a reflective dialogue with the world, or an expert activity based on years of experience and knowledge (Fallman, 2003; Lawson, 2004, 2005). With so many possible perspectives on design, it is no wonder that HCI scholars still struggle to successfully partner design activities with scientific inquiry. This struggle appears to manifest itself in two different ways:

1) Some HCI scholars fully embrace design, but emphasize IT artifacts and HCI practice so much that they may inadvertently limit the scientific or scholarly value of their work. In the worst cases, they may produce what Ellis and Dix (2006) refer to as, "I did this and it's cool," studies. Such work, which can be highly innovative from a technological standpoint, can be interesting to HCI practitioners and scholars alike. Yet when considered from a theoretical, scientific, or scholarly standpoint, the "I did this and it's cool" study tends to be narrowly targeted toward engineering-oriented disciplines where innovative developments in software or hardware design are valued. Despite having great potential to facilitate the study of human interactions with innovative technologies, real focus on the human experience tends to be overlooked in such work. This can be clearly seen in Ellis and Dix's (2006) review of design papers from the information visualization (IV) sub-discipline of HCI. They note how frequently appears the concluding phrase, "we intend to undertake a thorough user evaluation," (Ellis & Dix, 2006), suggesting an over-emphasis on design and the finished IT artifact with a corresponding under-emphasis on human-centered evaluation and scholarly contributions outside of the technological arena.

2) On the other hand, the reverse problem has also been noted (Iivari, 2007), particularly within HCI communities that come from an IS perspective (HCI in MIS) where design is sometimes considered atheoretical and so not science. These scholars gravitate towards natural, psychological, or social science approaches to the discipline that may not always complement design activities very well. HCI scholars from both HCI in MIS and more

design-oriented HCI traditions have warned about this exclusion of design, suggesting that HCI should not be considered a pure social or psychological science because of the uniqueness and value of its long tradition of design (Fallman, 2003; Hevner, March, Park, & Ram, 2004; Iivari, 2007; Mackay & Fayard, 1997; March & Smith, 1995; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007; Zimmerman, Forlizzi, & Evenson, 2007). Benbasat (2006) argues HCI scholars should, "learn how to design the interaction or the interface between individuals or groups and the technological artifact in order to assist practitioners," a clear call for more and better design outcomes in HCI. Nonetheless, many in these HCI communities prefer to study existing technologies using well-established social science research methodologies, rather than act with a designer's instinct to create their own IT artifacts for study.

In response to this predicament, some scholars have contributed to a growing body of literature on how design activity can become a useful scientific tool for HCI scholars. This body of literature crosses disciplinary boundaries; it has been developed by scholars situated directly in the HCI community itself, scholars from highly related communities like IS, and even by scholars in seemingly unrelated fields like education (e.g. Amiel & Reeves, 2008; Bayazit, 2004; Boling, 2010; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Joseph, 2004; Richey & Klein, 2007; Sandoval & Bell, 2004; Smith, 2010; Wang & Hannafin, 2005).

This dissertation study adds to these ongoing efforts, suggesting another way to think about design activities and their resulting IT artifacts in the context of HCI scholarship, in particular by rethinking the predominant perspective on what design is and how designers work. The following literature review frames this contribution by covering three topics:

1. A brief discussion of science and scientific activity; a basis for discussion rather than a comprehensive exploration of the many intricacies of scientific philosophy.
2. Four discrete views of design; their strengths and weaknesses when used to frame HCI design and scholarly activities.
3. Five different views of design science drawn from the HCI and IS communities; current approaches to bringing design and scientific perspectives together in order to generate new knowledge.

2. Considering Science

It has been suggested (Cross, Naughton, & Walker, 1981) that there is no point at all to discussing design in the context of science until philosophers come to fixed agreement on what science is: “Attempts to equate ‘design’ with ‘science’ must logically be predicated upon a concept of science that is epistemologically coherent and historically valid. The history of the twentieth century debate in the philosophy of science suggests that such a concept does not yet exist,” (Cross et al., 1981). Achieving such coherence seems an unlikely proposition at best when one views the many volumes written on philosophies of science, knowledge, and inquiry in which there is little consensus to be found (Diesing, 1991). Just one example: contrast Popper’s (1996) view of science as long term, incremental effort to make and falsify assertions about the world against Kuhn’s (1996) historical perspective of science as paradigmatic and open to periodic revolutions in thinking (Cross et al., 1981; Mackay & Fayard, 1997).

Despite a lack of consensus, an ongoing discussion about design as it relates to science does exist among HCI, IS, design, and other scholars (e.g. Boling, 2010; Hevner et al., 2004; Hevner & Zhang, 2011; Lawson, 2005; Mackay & Fayard, 1997; March & Smith, 1995; Smith, 2010; Zimmerman et al., 2007). Instead of avoiding this conversation, this dissertation is an effort to contribute to it. Cross et al. (1981) are right to suggest that any such discussion should begin with some basic perspective on science. If cohesion does not yet exist at the philosophical level, still it is true that every year thousands of doctoral students earn their degrees and become scientists in a host of disciplines; these people go on to spend their time conducting research and producing scholarly, scientific knowledge according to the established standards of their respective fields.

Popper (1996), in his seminal work *Conjectures and Refutations: The Growth of Scientific Knowledge*, establishes an influential thesis: "We can learn from our mistakes." In this vein, he goes on to define science as follows: "A system is to be considered scientific only if it makes assertions which may clash with observations; and a system is, in fact, tested by attempts to produce such clashes; that is to say, by attempts to refute it," (Popper, 1996). Yet Diesing (1991) suggests that, while scientific knowledge may certainly come from observable data as Popper suggested, it can also come from aggregate data, conversations with subjects being studied, documents, and even a researcher's own experiences and reactions. One of his main points is that scientific knowledge advances through varying scholarly communities, each of which understand the creation of knowledge in different ways. "Multiple traditions or communities live side by side, more or less acrimoniously. The philosophers disagree on whether it is better to work steadfastly within a community and ignore the others, or to actively engage other communities in dialogue, each community exposing others' weaknesses and learning about its own problems from the others," (Diesing, 1991, p. 326).

The challenge of defining science is not limited to philosophers; the discussion continues even in practical methods literature. Babbie (2010), in *The Practice of Social Research*, acknowledges the often slippery notion of what science is, including many disagreements over exact definitions, and calls it simply, "a method of inquiry – a way of learning and knowing things about the world around us… it is a conscious, deliberate, and rigorous undertaking." Cresswell (2009), in *Research Design*, emphasizes research methodology, suggesting that, "research designs are plans and the procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis." Finally, Simon (1996), in his seminal work *The Sciences of the Artificial*, defines natural science as, "a body of knowledge about some class of things – objects or phenomena – in the world: about the characteristics and properties they have; about how they behave and interact with each other." He contrasts this with his definition of a proposed artificial science: a similar body of knowledge about artificial (man-made) things (Simon, 1996).

The notion of a "fourth paradigm" has been used to illustrate historical progression from empirical science (thousands of years old: the 1st paradigm), to theoretical science (hundreds of years old: the 2nd paradigm), to computational science (a few decades old: the 3rd paradigm), to eScience and data exploration (happening now: the 4th paradigm) (Gray, 2009). Early science was highly observational in nature, and early scientists spent many hours cataloguing that which they could observe in nature; theirs was a descriptive science (Gribbin, 2002). Later, these observations were placed into frameworks – theories – which gave them much greater explanatory and predictive power. Scientific theories are the basis for many of the assertions which scientists make and test (Babbie, 2010; Creswell, 2009; Diesing, 1991; Gregor, 2006; Popper, 1996; Shoemaker, Tankard, & Lasorsa, 2004; Suppes, 1967). Currently, computational tools and vast repositories of data are helping to make our observations and theories even more powerful (Gray, 2009).

Observation and theory, then, even though these are defined broadly and understood differently from scholarly community to scholarly community, are the scientific way of understanding the world. Interestingly, notions of observation and theory parallel a distinction between two traditional scientific models: the deductive and the inductive. Deductive science attempts to, "deduce properties of the real world from theory," while the inductive mode, "attempts to induce or generalize theories from observations of real world phenomenon," (Mackay & Fayard, 1997). In the deductive model, scientists generate hypotheses (assertions) to explain phenomena, and then test them. This is the most general model of science, and dates to Galileo. It is the basis of experimental science. In the inductive model, the purpose is to develop descriptions (but not always explanations) of the real world. This model is the basis for fields like anthropology or sociology (Mackay & Fayard, 1997).

Both approaches value reliability (results that can be replicated by others) and validity (results that can be generalized beyond the specific circumstances of the test) because both approaches ultimately deal with a real world that contains variable conditions which must be accommodated (Mackay & Fayard, 1997). In the reality of the scientific community, some researchers work deductively, some work inductively, and some combine both methods (Creswell, 2009); deductive inquiry can lead a scholar to try inductive approaches, and vice versa. The interplay of all these methods and approaches to inquiry are what ultimately accumulate our knowledge of the world.

The deductive and inductive models have been criticized and refined over the years. Popper (1996) highlights an important limitation of the deductive model: the possibility always exists that an assertion will fail if tested under conditions that are different from those where it succeeded. So at best, an assertion or hypothesis can only be corroborated by evidence, and never proved to be true. Rather than premising tests as a way of proving assertions, the deductive model in its modern form is premised around disproving them by providing counterexamples that refute the original assertion (Babbie, 2010; Creswell, 2009; Popper, 1996).

The inductive model has also been criticized, particularly for its notion that observations of real-world phenomenon (particularly in the social world of human beings) can be undertaken in a completely unbiased manner without influencing the outcome(s) of those observations. Many anthropologists and sociologists now suggest that researcher biases simply be acknowledged over the course of conducting and disseminating inductively produced scientific work (Mackay & Fayard, 1997). Some scholarly communities encourage participatory approaches, where the researcher’s own perspectives become an integral part of the work (DeWalt & DeWalt, 2002).

In this dissertation, and based on existing discussions of science and science philosophy, scholarship is understood broadly as a systematic approach to producing knowledge or understanding about the world. Diesing’s (1991) suggestion that scientific practices vary from community to community and can benefit from interdisciplinary critique and collaboration is a useful point of view in the upcoming discussion. Design science is an approach to inquiry, not a method or epistemology, per se, and so this work acknowledges the variable interpretations of what it is to undertake scholarly inquiry. Though this research is written specifically with the HCI community in mind, other communities of inquiry may also eventually benefit from a formal discussion of design science. What is important is that design science pairs scholars – however they define themselves, whatever methods of inquiry they subscribe to – with designers and design activity. With that in mind, the next section turns to an exploration of design thinking.

3. Design Thinking: Four Views

Over the years, a number of researchers have explored design thinking within the HCI community (e.g. Carroll, 1997; Fallman, 2003; Forlizzi, Zimmerman, & Evenson, 2008; Forlizzi, Zimmerman, & Stolterman, 2009; Mackay & Fayard, 1997; Stolterman, 2008; Wright, Blythe, McCarthy, Gilroy, & Harrison, 2006; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman, Stolterman, & Forlizzi, 2010). HCI scholarship frequently revolves around design activity, and many of these authors argue that it is unhelpful and possibly detrimental to understand the discipline strictly as a natural or social science. Yet, at the same time, there is a relative lack of clarity about what design thinking in HCI is and what it should be. Introducing design activity into scientific practices can make it difficult to distinguish HCI practice from HCI scholarship. An important first step to exploring design as a vehicle for knowledge generation in HCI is to understand different perspectives on what design is.

In this section, four distinct views of design are presented. Each of these views is espoused by prominent scholars within the HCI and design communities. Fallman (2003) presents thorough discussions of three of the four views of design in his exploration of design thinking, sketching, and prototyping within the HCI discipline: the *conservative* view, the *romantic* view, and the *pragmatic* view. A fourth view of design, espoused by Lawson (2004, 2005), is the *expert* view.

3.1. The Conservative View

Fallman's (2003) conservative view of design is drawn from works by Simon (1996) and others, who take a predominantly engineering-centric perspective on design (e.g. Alexander, 1964; Löwgren, 1995; Stolterman, 1994). In this view, "design is thought of as a scientific or engineering endeavor, borrowing methodology and terminology from the natural sciences, mathematics, and systems theory, drawing on a philosophical base in rationalism," (Fallman, 2003). In the conservative view, there is a problem to be solved, and design should progress in an orderly manner through a series of steps from analysis of the problem to synthesis of a solution to its final evaluation. The conservative view of design sees design processes as structured and scientific, built around guidelines rather than the knowledge, judgment, and skills of the individual designer (Fallman, 2003; Löwgren, 1995; Stolterman, 1994). "This tends to deemphasize the role of the designer, striving towards a disembodied design process built on structured methods and externalized guidelines rather than on the skills and judgment of individual designers," (Fallman, 2003). In short, designers in the conservative view are somewhat like interchangeable units – one designer is as good as any other, and all should be able to justify their design decisions rationally, based on evidence that can be empirically collected and validated in scientific ways.

The conservative view is frequently (but often silently) adopted when discussing design as a scholarly activity because its orderly, structured outlook seems to conform closely to the ideal of the scientist. Using Popper (1996) as a guide, the design becomes an assertion and its successful or unsuccessful use becomes a test.

Despite its widespread adoption in some quarters, the conservative view has been critiqued as being too didactic, reductionist, linear, and inflexible – an unrealistic way of approaching design problems that tries to impose too many guidelines, rules, and scientific laws into activities that may not always be so formally structured (e.g. Alexander, 1971; Brooks, 1975/1995; Carroll, 1997; Carroll & Campbell, 1989; Cross et al., 1981; Dillon, 1995; Ehn, 1988; Fallman, 2003; Lawson, 2005; Stolterman, 2008). Many highly successful designers don't work in the manner described by the conservative view. Furthermore, reliability and validity are not necessarily important goals to designers, despite their emphasis in the conservative view. Two designers looking at the same problem usually will not (and often need not) produce the same design to address it; indeed, in many cases novel or innovative approaches will preferred over reliability in design. Designs are often highly contextualized, obviating the need for generalizability as well.

3.2. The Romantic View

The romantic view is almost the polar opposite of the conservative view, and Fallman (2003) draws from a different set of literature by Coyne (1995, 1999), Louridas (1999), Schön (1987), and Stolterman (1994) when describing it. In the romantic view, designers are characterized as "creative geniuses," and "imaginative masterminds," who have "almost magical abilities of creation," (Fallman, 2003). They are creative individuals with unusual talents, and their imagination is perceived as superior to abstract reasoning, their creativity surpasses rational problem solving. Designers in the romantic view are fairly compared to "painters, composers and poets, rather than with scientists or engineers," (Fallman, 2003). The romantic view inflects a degree of mystery and mysticism onto design activities; in this view, it is not possible to fully understand the process of design, nor is it entirely necessary to understand. Rather, like great athletes, designers may actually lose some of their masterful ability when they think too much about what it is that they are doing. Louridas (1999) captures the romantic view in the following statement: "Design is related to art. This relation is what makes design what it is: design is not just about the creation of useful artifacts: it is equally about the creation of beautiful artifacts. Utility and aesthetics intertwine in the design process; but it is not clear how." Ultimately, the romantic view of design treats designers as artists and substitutes individual creativity and innovation for the methodology, control, and logical reasoning seen in the conservative view (Fallman, 2003).

Just as the conservative view has been critiqued for having too much structure, the romantic view can be critiqued for indulging in the opposite: too little. While the romantic view holds weight among many artists, it offers little in the way of explanatory power for the HCI scholar who seeks to leverage design as a research tool. If design processes cannot (and perhaps should not) be explicated, then design becomes entirely opaque – a "black box" from which little useful knowledge can escape (Fallman, 2003). Designs that result from this view may be artistically beautiful and even functional, but can be unhelpful when exploring design problems and research questions.

3.3. The Pragmatic View

Fallman's (2003) third and final perspective on design is the pragmatic view, developed out of thinking by Coyne and Adrian (1991), Jones (1970), Lévi-Strauss (1966), and Schön (1983). The pragmatic view of design emphasizes the designer and the design within a specific and highly contextualized design situation. This view sees design as carried out somewhere in particular, located in "a world which is already crammed with people, artifacts, and practices, each with their own histories, identities, goals, and plans," (Fallman, 2003). Designers in the pragmatic tradition must iteratively interpret how their designs impact the situation at hand, and how the situation influences the design (Coyne & Adrian, 1991). Instead of theories and methodology, "reflection-in-action… is central to the 'art' by which practitioners sometimes deal well with situations of uncertainty, instability, uniqueness, and value conflict," (Schön, 1983). The pragmatic view is, in some ways, a version of the romantic view, with structure superimposed through a process of reflection. Design is no longer a black art undertaken in a black box. Though it may be entirely unscientific, it can still be explored through reflective practice.

Because the pragmatic perspective emphasizes that design problems are always highly situated within specific contexts, this makes it very difficult to extrapolate more general knowledge from design activities. In fact, the pragmatic view intentionally seeks out the most unique and challenging situations possible (Fallman, 2003; Schön, 1983). This "situatedness" can be interesting, but science values reliability and validity. In the conservative view, requirements for reliability and validity were so rigid as to make them alien to the designer. In the pragmatic view, they are largely avoided: designs are unable to be replicated or generalized because they are developed in utterly unique situations.

3.4. The Expert View

Lawson (2004, 2005; Lawson & Dorst, 2009) presents a fourth view of design – call it the "expert" view. He points out that designers rarely become recognized for their important contributions until they are middle aged or older, a sharp contrast to other fields like mathematics or athletics, where major contributions are expected early in life. To Lawson (2004), this suggests that design is a field where accumulated experience has a critical role to play, a view reflected by other design scholars (e.g. Boling, 2010; Christiaans & Venselaar, 2005; Cross, 1999, 2004, 1984; Cross et al., 1981; Gero, 1990; Smith, 2010; Stolterman, 2008). Drawing upon his years of experience as an architect, as well as numerous empirical studies on the psychology of design practice (e.g. Akin, 1986; Darke, 1979; Eastman, 1970; Hillier, Musgrove, & O'Sullivan, 1972; Lawson, 1979; Rowe, 1987), Lawson (2004) goes on to explicate his view of design. He suggests that design is about gathering experience; designers navigate a common language by using commonly understood "shorthand" methods of communication – sketches, phrases, and single words. This shorthand represents vastly complex design ideas, and both it and the ideas themselves are only understandable by those with years of accumulated design experience. Some of this experience is formal design training, but much of it is an accumulation of prior precedent as well as design techniques, tricks, and strategies.

Lawson (Lawson, 2004, 2005) uses a chess analogy to explain the way expert designers approach a problem. Master chess players can sometimes amaze onlookers by simultaneously playing and winning several chess games against multiple novice opponents. This feat is accomplished because master chess players – unlike non-experts, who see each chess game as unique – learn to recognize how similar configurations of pieces on the board will often recur time and again in different games. Instead of paying close attention to each of the games they are playing simultaneously, expert chess players draw upon an internalized library of potential board configurations (prior precedent) and select from a repertoire of moves (techniques, tricks, strategies) to address those configurations.

In similar fashion, designers must become expert at recognizing problems as variations on more common types, drawing upon a vast accumulation of prior precedent, and acting from that precedent using their repertoire of tricks, strategies, or techniques to address the problem. The more expert the designer, the deeper the well of accumulated precedent and strategy and the more proficiently the act of recognizing and acting can be done. "The argument here is that recognizing design situations is one of those key skills. Seeing some kind of underlying pattern or theme enables a designer to recognize this and make a connection with some precedent in the episodic memory," (Lawson, 2004). Similarly, Wolf et al. (2006) describe how designers employ a process of "rational judgment." Laxton (1969) describes a relevant model for design education premised on an analogy to a hydroelectric power plant. Design education first requires an accumulation of experience and knowledge (the reservoir). Later, this reservoir can be used to inspire or initiate ideas (the generator).

The expert view of design also accommodates a more interesting situation – when the expert designer confronts a challenge that is outside the scope of their reservoir of prior precedent and design strategies – a "wicked" problem. Lawson (2004) illustrates this situation using the chess master analogy once more: "To beat another chess master who is also recognizing [a design situation] and similarly has a vast pool of precedent and gambits to rely on, they need to create something new, original and surprising. This sounds remarkably like what we also expect from expert designers." Laxton (1969) continues with the hydroelectric analogy, suggesting that students must eventually develop the ability to critically evaluate and discriminate between their ideas, interpreting them for new contexts (the transformer). For the expert designer facing a demanding problem, recognizing situations and enacting known design strategies will not be enough. Rather, prior precedent and known strategies must be reformulated and creatively adapted to accommodate difficult but interesting design challenges.

The "expert" view of design encompasses aspects of the three previously discussed views. From the pragmatic view, it adopts the notion of reflection, as situations in the world are analyzed and recognized, while a large reservoir of precedent and experience is tapped for meaningful reference material. The reliance upon a repertoire of design techniques, tricks, and strategies (i.e. expert knowledge on design process) has some relation to the conservative view of design, which dictates that design decisions are made in a defensible or justifiable way. In the conservative view, design techniques are developed out of theory and evaluation; in the expert view, they also come from past failures, successes, and accumulated experience. In both cases, the techniques adopted into a design are explainable and testable on their merits. However, the expert view of design also includes an element of the romantic, as design mastery requires inventive reconceptualization of design problems, creative adaptation of precedent, and inspired creation of new solutions (i.e. expert knowledge that is comprehensive enough to engender innovation). Some aspects of an expert designer's innovation may be explainable by reflecting upon the precedent from which it came, but as in the romantic view, there remains an element of mystery or mysticism to the process. The expert view of design also acknowledges the artistic and aesthetic elements of design (Lawson, 2005), as well as the end goal of producing "functional art," a perspective that is most similar to the romantic view.

Unlike the conservative view, which tends to reduce the designer to an interchangeable cog in a linear design process dictated by scientific rigor and methodology, the expert view might be critiqued for elevating the designer too much, creating what Lawson (2005) calls a "cult of the individual." Expert designers are not interchangeable, and each one carries his or her own reservoir of known precedent, techniques for addressing design problems, and the ability to expand upon these resources (or not) as needed; a designer may or may not be an expert, and there may exist different levels of design expertise. This has the potential to develop into a frustrating (but likely common) situation where, "the skills and abilities of the designer determine the quality of the final [product]," (Löwgren, 1995), a sentiment echoed by Fallman (2003). While the conservative view may downplay the role of the designer to unrealistic levels, the expert perspective may engender circumstances where scientific outcomes are beholden to his or her expertise.

Specialization is another limitation of the expert view. For the most part, it is not possible to become truly expert in more than just a few things, so the expert view implies that a designer's reservoir of prior precedent and technique will be centralized around some specific design domain: graphic design, interaction design, user experience design, web development, software engineering, mechanical engineering, electrical engineering, etc. (Lawson, 2005). In the case of scholarly HCI design activity, this could result in a more narrow view of the problem than is desirable, as each designer views it through the lens of their own particular experience and expertise. However, a broader view might require a veritable panel of experts. Less realistically, the HCI scholar might also attempt to become an expert in various design specializations him or herself.

3.5. Summary of the Four Views of Design

Fallman (2003) includes a summative chart, adapted from Cross (1984). This chart is helpful to reproduce here, with the addition of the fourth expert view of design (Lawson, 2004, 2005):

	Four Views of Design			
	Conservative	Romantic	Pragmatic	Expert
Designer	An information processor	A creative imaginative genius; an artist	A reflective, self-organizing system	Accumulator of knowledge; an expert
Problem	Ill defined and unstructured; to be defined	Subordinate to the final product	Unique to the situation; to be set by the designer	A variation on prior problems; explore past precedent to understand
Process	A rational search process; fully transparent	Largely opaque; mystical	A reflective conversation; a dialogue	Recognition of similar problems; shorthand to communicate; use repertoire of design strategies to solve
Product	A result of the process	A functional piece of art	An outcome of a dialogue; integrated into the world	A creative twist on past approaches
Knowledge	Guidelines; design methods; scientific laws	Creativity; imagination; craft; drawing	How each problem should be tackled; compound seeing; experience	Design examples; precedent; known strategies; experience
Role Model	Natural sciences; engineering; optimization; theory	Art; music; poetry; drama	Human sciences; sociology	Architecture; product design; graphic design; interaction design

Table 2.1. Four views of design. Adapted from Fallman (2003) and Cross (1984). Additional information from Lawson (2004, 2005).

4. Design Science: An Overview and Four Perspectives

Design science is a way of adapting design activities to scientific ends. It is the challenge of bringing together two different mindsets – that of the designer, that of the scientist – and directing them toward the same outcome – the generation of new knowledge. As previously described, there are varying perspectives on what it is to do design, and as this section will show, varying perspectives also on how design activities should be adapted to scientific purposes.

The term “design science” comes from IS and the HCI in MIS communities, where it labels a sizeable body of scholarly work seeking to justify design in a disciplinary community dominated by the social-psychological science mindset (e.g. Hevner, 2007; Hevner et al., 2004; Hevner & Zhang, 2011; Iivari, 2007; Iivari & Venable, 2009; Järvinen, 2007; March & Smith, 1995; Markus, Majchrzak, & Gasser, 2002; Nunamaker, Chen, & Purdin, 1990; Peffers et al., 2007). The desire to rationalize design for the IS community has shaped these discussions, and they share – to varying degrees – a core belief that design activities in IS can be viewed as scientific activities, as long as they are properly framed and undertaken in an appropriate context. Subsequently, design science in the IS tradition is almost always approached with a conservative view of design in mind; to successfully argue that design can be science it seems necessary to these authors to superimpose upon it the kind of methodological rigor espoused in the conservative view. Desire for scientific control over the design process is seen within HCI discussions of design science as well; Fallman (2003) suggests that in many HCI studies, "the design process tends to remain implicit as researchers are embarrassed by not being able to show evidence of the same kind of control, structure, predictability, and rigorousness in doing design as they are able to show in other parts of their research... the act of actually bringing forth the prototype – the design process – seems often obliterated from descriptions of research projects; research prototypes just seem to 'happen.'"

Other views may not use the term "design science," but are related to (though distinct from) the IS perspective. Thus it is convenient to label them also as design science, while simultaneously acknowledging their differences from the IS perspective. One such view comes from the HCI discipline. Carroll (1997) and several other scholars (Carroll & Campbell, 1989; Carroll & Rosson, 1992; Dillon, 1995) suggest that IT artifacts are equivalent to psychological theories. Like the IS view of design science, their artifact-as-theory view justifies design as science, but emphasizes the outcomes of design (design as a thing; an IT artifact) rather than the process of design (design as an activity; design as a way of working or knowing). In the design-as-artifact view, design processes as a form of science are downplayed; these activities, while important, are seen as distinct from science. However, when finished, the IT artifact itself contains a vast store of theoretical information about users, usability, and psychology. That is, it encapsulates scholarly knowledge and can become the basis for future scientific assertions and tests.

Also working within the HCI discipline, some scholars (e.g. Forlizzi et al., 2008; Forlizzi et al., 2009; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman et al., 2010) have avoided making the argument that design can be considered as science, suggesting instead that design can be valuable to science because of the unique perspective that designers bring to knowledge generation. In this view, interaction designers take center stage as coordinators of a cooperative scholarly effort between engineers, anthropologists, and behavioral scientists. This perspective on design science is a departure from the prominent conservative view of design found in the previous viewpoints. It stems from a mix of the romantic, pragmatic, and expert designer standpoints.

A final perspective on design science, situated within HCI and other expert-oriented design disciplines, argues that design is a contributor (but not equivalent) to science (Fallman, 2003; Lawson, 2004, 2005; Lawson & Dorst, 2009). In this view, sketches, as well as their HCI counterparts – prototypes – are viewed as much more than simple visual tools. Rather, they are conversations that take place between a designer and a problem space; they are a way of "designerly" thinking and a form of inquiry. As a form of inquiry, sketches and prototypes have a great deal to contribute to the scientific process. It is not clear exactly which design perspective this view draws upon. Fallman (2003) suggests that elements of the conservative, romantic, and pragmatic views are equally valid and useful, while Lawson (2004, 2005; Lawson & Dorst, 2009) writes on prototyping from his own perspective, which is referred to here as the expert view.

4.1. Design Science in Information Systems

In the IS (as well as HCI in MIS) view, design science is an approach to scholarly study where design activities – usually viewed through the conservative lens – are framed as scientific activities. The design, development, and evaluation of an IT artifact becomes a vehicle for scholarly knowledge generation. System development is viewed as a research methodology (Hevner, 2007; Hevner et al., 2004; Hevner & Zhang, 2011; Iivari, 2007; March & Smith, 1995; Nunamaker et al., 1990; Peffers et al., 2007; Simon, 1996; P. Zhang & Galletta, 2006a, 2006b). The term IT artifact has been defined in various ways. In the IS design science perspective a relatively broad definition is common. Hevner, et al. (2004) describe IT artifacts as, "constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems)." Thus, in the IS view an IT artifact can be more than just an instantiated information system or technology.

The IS view of design science has its roots in Simon's (1996) *The Sciences of the Artificial*, an exploration of the study of man-made things in which design thinking plays an important role. According to Simon (1996, p. 111), "everyone designs who devises courses of action aimed at changing existing situations into preferred ones." In Simon's (1996) view, design is a process of satisficing to find alternatives. Rather than seeking the optimal preferred situation, designers navigate a vast landscape of *possible* solutions, looking for those that are good enough within a reasonable amount of time. This is because designing and evaluating every possible solution is infeasible (even impossible). Knowing exactly how many alternatives there are and what they are is not very important to this process; it is more important to find a reasonably good solution fairly quickly than it is to find the optimal solution after a very long (even impossibly long) time.

Like Lawson (2004, 2005), Simon draws upon the game of chess as an example. He describes how a chess player could never analyze every possible move and its impact on the game when deciding where to position a piece (an operation encompassing something on the order of 10^{120} calculations to achieve). Instead, like a designer, the chess player looks for satisfactory moves that make a winning condition more likely. In Lawson's (Lawson, 2004, 2005) view, this would be predicated on a reservoir of expert knowledge from a variety of sources including design precedent; Simon (1996), however, adopts the conservative view of design. He dictates a seven-step curriculum that any designer should know. This curriculum is heavily informed by the view that design should be methodological, controlled, and rigorous:

1. Utility theory and statistical decision theory as a logical framework for rational choice among given alternatives.
2. The body of techniques for actually deducing which of the available alternatives is the optimum.
3. Adaptation of standard logic to the search for alternatives.
4. The exploitation of parallel, or near-parallel, factorizations of differences.
5. The allocation of resources for search to alternative, partly-explored action sequences.

6. The organization of complex structures and its implication for the organization of design processes.
7. Alternative representations for design problems, (Simon, 1996, pp. 118-127).

In Simon's (1996) view, knowledge of these key design methods establishes a common ground on which different groups can communicate with each other; design becomes a way that engineers and musicians can speak in the same language around their point of commonality. When viewed through the lens of other design perspectives, however, this curricula seems rather divorced from actual design practice and design knowledge (Cross et al., 1981; Fallman, 2003; Lawson, 2004, 2005; Lawson & Dorst, 2009). Cross et al. (1981) go so far as to suggest that, "The examples of the elements of this emerging doctrine that Simon offered included several that are now regarded as of dubious value in a design context; for example, methods of optimization borrowed from management science (sic), and methods of problem structuring based on the hierarchical decomposition techniques developed by Manheim and Alexander."

Nonetheless, Simon's (1996) view has much to offer and has been greatly expanded upon in recent years by a variety of IS scholars (e.g. Hevner, 2007; Hevner et al., 2004; Hevner & Zhang, 2011; Iivari, 2007; March & Smith, 1995; Nunamaker et al., 1990; Peffers et al., 2007). In their view, as in Simon's (1996), the IT artifact is inherently artificial (Simon points out that this label is not intended to be derogatory); it is a human-produced (as opposed to naturally occurring) construct, model, method, or instantiation. Design science is an approach to studying these artificial things by designing and evaluating them under appropriate circumstances. Like Simon (1996), the modern IS approach frames design as a science. Hevner et al. (2004) and March and Smith (1995) draw a clear contrast between the natural or behavioral sciences and design sciences. According to Hevner (2004), "The behavioral-science paradigm has its roots in natural science research methods. It seeks to develop and justify theories (i.e., principles and laws) that explain or predict organizational and human phenomena surrounding the analysis, design, implementation, management, and use of information systems." March and Smith (1995) agree, but step back slightly from Hevner's (2004) IS centric perspective, suggesting that natural or behavioral science, "is aimed at understanding reality. Natural scientists develop sets of concepts, or specialized language, with which to characterize phenomena. These are used in higher order constructions – laws, models, and theories – that make claims about the nature of reality. Theories – deep, principled explanations of phenomena (Achinstein, 1968) – are the crowning achievements of natural science research."

If the natural and behavioral sciences are about the nature of reality, design science is about the nature of man-made things. According to Hevner et al. (2004), "The design-science paradigm has its roots in engineering and the sciences of the artificial (Simon, 1996). It is fundamentally a problem solving paradigm. It seeks to create innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished." March and Smith (1995) further suggest that, "Whereas natural science tries to understand reality, design science attempts to create things that serve human purposes. It is technology-oriented. Its products are assessed against criteria of value or utility - does it work? Is it an improvement?" Gregory (1967), an early leader in the design methods field, described the differences between design and science as well (somewhat paradoxically, given his desire to achieve a methodology for design analogous to the scientific method): "The scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things of value which do not yet exist. Science is analytic; design is constructive," (Gregory, 1967). These sentiments are similarly reflected in the HCI discipline: "HCI cannot be considered a pure natural science because it studies the interaction between people and artificially-created artifacts, rather than naturally-occurring phenomena, which violates several basic assumptions of natural science. Similarly, HCI cannot be considered a pure design discipline because it strives to independently verify design decisions and processes, and borrows many values from scientists... a multidisciplinary field like HCI must necessarily draw from and benefit from both," (Mackay & Fayard, 1997).

Despite these acknowledged differences, a central argument of the IS view of design science seems to be that design activities are scientific activities, as long as they are properly framed within an appropriate context. In this view, the context is almost always organizational. Hevner et al. (2004), in their definition of design science argue that it is the "other side of the IS research cycle." It is a way to, "create and evaluate IT artifacts intended to solve identified organizational problems." This emphasis on organizational problems is reflected in (Hevner, 2007; Iivari, 2007; March & Smith, 1995; Nunamaker et al., 1990; Peffers et al., 2007; Simon, 1996). For HCI in MIS scholars, the context is sometimes broader and possibly non-organizational, encompassing personal technology use, unique cultural contexts, or other human-computer interactions that are of interest to the HCI (and not just IS) community. Even when this broader view is adopted, however, design scientists and HCI scholars who work from the MIS perspective still continue to have a predominantly business, managerial, and organizational point of view (P. Zhang et al., 2002; P. Zhang & Li, 2005; P. Zhang, Li, Scialdone, & Carey, 2009). Shneiderman (2006), for example, in his foreword to *Human-Computer Interaction and Management Information Systems: Foundations*, a key HCI in MIS text, emphasizes the “workplace,” “managers,” “employees,” “business decision makers,” and “customers.”

Design science activity in the IS tradition, in addition to being contextualized in predominantly organizational settings, is also framed around theory and observations that can make and test assertions about the world. At the same time, design science assertions and tests are distinctly different from those found in the natural sciences; instead of testing how well an assertion explains something about the world, assertions and tests in design science are about determining success or failure (Hevner, 2007; Hevner et al., 2004; Iivari, 2007; March & Smith, 1995; Nunamaker et al., 1990; Peffers et al., 2007) – did the proposed design solve the problem it was intended to address?

Assertions and testing which seek to prove success or failure have a deep impact on the kinds of problems that IS design science can and should address. Simple problems or problems that have already been solved are to be avoided; the systems that can be designed to address these problems are either uninteresting in their triviality, or are replications of prior work that do not generate much (if any) new knowledge. Testing obvious or known systems is not a fruitful endeavor for the IS design scientist. Rather, IS design science should address very challenging problems (Hevner, 2007; Hevner et al., 2004; March & Smith, 1995; Peffers et al., 2007), those sometimes referred to as “wicked” problems in the engineering disciplines because they defy easy or obvious answers

(Brooks, 1987, 1996; Rittel & Webber, 1984). According to Hevner et al. (2004), such problems are typically characterized by: 1) "Unstable requirements and constraints based upon ill-defined environmental contexts, 2) Complex interactions among subcomponents of the problem and its solution, 3) Inherent flexibility to change design processes as well as design artifacts (i.e., malleable processes and artifacts), 4) a critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions, and 5) a critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions."

Scholarly contributions are an expected outcome of design science activities in the IS view as much as any other. In some non-IS disciplines, IT artifacts themselves may be considered such a contribution (Hevner et al., 2004); for example, information visualization, a sub-discipline of HCI, has a strong tradition of design-oriented research where presentation of a designed system to illustrate some new technique or visualization capability is considered a meaningful and important scholarly contribution (Ellis & Dix, 2006; Shneiderman & Plaisant, 2006; Yi, Kang, Stasko, & Jacko, 2007). Much of the conceptual writing on design science in IS makes the argument that IT artifacts should be similarly viewed as scholarly outcomes within the IS community. To this end, Hevner et al. (2004) suggest that a high quality design science study should contain one or more of the following: 1) the designed artifact itself, 2) models, methods, or instantiations that improve the foundational knowledge base, or 3) creative development and use of evaluation methodologies. This recommendation suggests that design science outputs should be a mix of instantiated artifacts themselves and more traditional scholarly contributions. According to Hevner et al. (2004), instantiations produced through design science research are an important scholarly output because they, "demonstrate feasibility, enabling concrete assessment of an artifact's suitability to its intended purpose. They also enable researchers to learn about the real world, how the artifact affects it, and how users appropriate it." In practice, however, the IS version of design science has been strongly criticized for lacking very many findings that are of real interest in practice (whatever their value to scholars), and for becoming too invested in theory-based research (Iivari & Venable, 2009).

Several different models of design science in the IS tradition have been proposed, four of which (Hevner, 2007; Järvinen, 2007; Nunamaker et al., 1990; Peffers et al., 2007) will be discussed in the next sections. It is worth noting that, though design science and its various models have been advocated for years in IS, it is still common to read variations on this typical lament: "While design, the act of creating an explicitly applicable solution to a problem, is an accepted research paradigm in other disciplines, such as engineering, it has been employed in just a small minority of research papers published in our best [IS] journals to produce artifacts that are applicable to research or practice," (Peffers et al., 2007).

Complementary to formalized design science models, Hevner et al. (2004) offer the following broad guidelines for design science. These guidelines present a more practical viewpoint on design science than the seven curriculum items suggested by Simon (1996); they are a guide to doing design science, not just an ontology of things that designers should know:

1. An innovative, purposeful artifact must be created.
2. The artifact must address a specified problem space.
3. Thorough evaluation of the artifact is crucial.

4. The artifact should be innovative; it should solve an unsolved problem, or solve it in a more efficient or effective way.
5. The artifact must be rigorously defined, formally represented, coherent, and internally consistent.
6. A mechanism for exploring the problem space should be posed and enacted in order to find an effective solution.
7. The results of the design science research should be communicated effectively to both practitioners and other researchers within both the IS field and the problem space (Hevner et al., 2004).

The IS view of design science has analogues in the education community, where it is written about and sometimes practiced in a similar fashion to IS. Variations on the general concept are known by a variety of names: "design-based research," (Amiel & Reeves, 2008; Joseph, 2004; Sandoval & Bell, 2004; Wang & Hannafin, 2005), "design and development research," (Richey & Klein, 2007; Smith, 2010), "design cases," (Boling, 2010), or "design experiments," (Cobb et al., 2003). Design and development research, in particular, closely mirrors much of the current thinking in IS design science scholarship. Despite this, there is limited overlap between the two literatures.

4.1.1. A Three Cycle Model of Design Science

Hevner (2007; Hevner et al., 2004) describes a three cycle model of design science to show how these seven objectives can be achieved. The three cycles in the eponymous model are: relevance, design, and rigor. The relevance cycle, "bridges the contextual environment of the research project with the design science activities," the design cycle, "iterates between the core activities of building and evaluating design artifacts and processes of the research," and the rigor cycle, "connects the design science activities with the knowledge base of scientific foundations, experience, and expertise that inform the research project," (Hevner, 2007). The rigor cycle is suggested to be particularly important to this model. Hevner (2007) cites Iivari (2007), who argues that, "It is the rigor of constructing IT artifacts that distinguishes Information Systems as design science from the practice of building IT artifacts." This notable statement summarizes the IS view of design science: design, when undertaken rigorously, correctly framed, and applied in an appropriate context, can be treated as a science in and of itself. The notion of rigor in this view seems to be drawn from the conservative perspective on design.

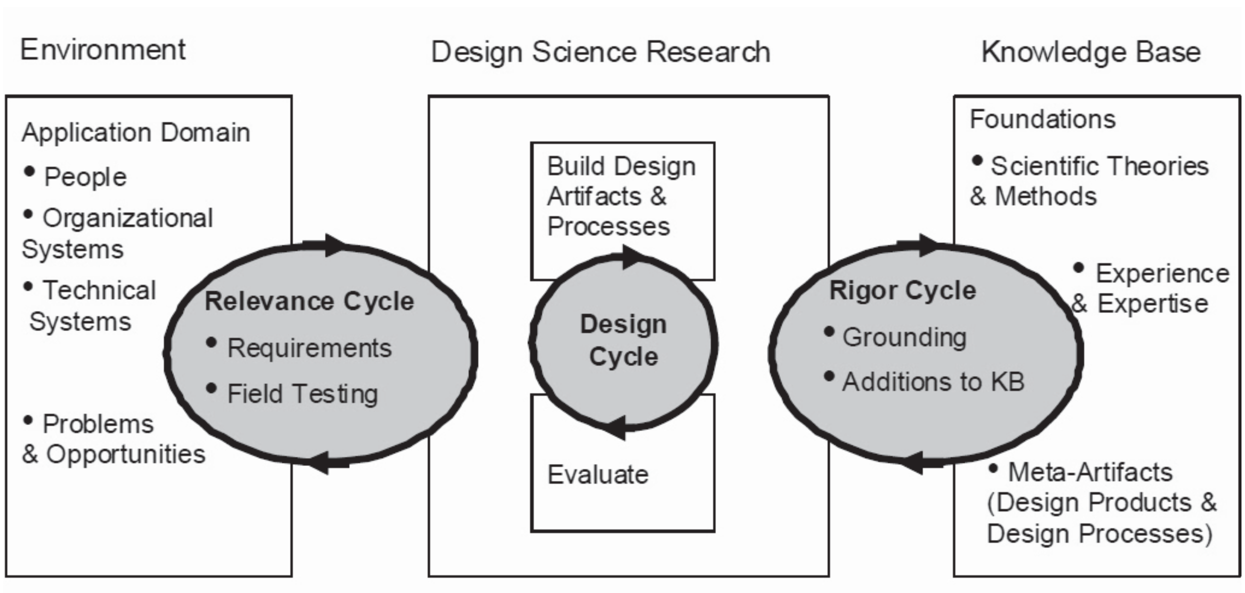

Figure 2.1. A three cycle model of design science; from Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, 19(2). Used by permission.

In his three cycle model, Hevner (2007) acknowledges an important distinction between scientific outputs and design outputs: "Additions to the knowledge base as results of design science research will include any extensions to the original theories and methods made during the research, the new meta-artifacts (design products and processes), and all experiences gained from performing the research and field testing the artifact in the application environment.

Research contributions to the knowledge base are key to selling the research to the academic audience just as useful contributions to the environment are the key selling points to the practitioner audience," (Hevner, 2007).

4.1.2. The Design Science Research Model (DSRM)

Peffers et al. (2007) describe a design science research model (DSRM) that also emphasizes the process of doing design science. The DSRM consists of six key steps: 1) Identify problem and motivation to solve it, 2) define objectives for a solution, 3) design and development: create the artifact, 4) demonstration (show that the artifact solved the problem), 5) evaluation (measure how well the artifact solves the problem), and 6) communication (disseminate knowledge).

While presented in a relatively linear fashion from step one to step six, the Peffers et al. (2007) DSRM is notable for emphasizing various entry points to the design science research process. These include problem-centered initiation (where a problem is identified as needing a solution), objective-centered initiation (where the advantages of a better artifact motivate its design), design and development motivated initiation (where technical challenges initiate the design process), and client/context initiation (where a specific client or context suggests the need for design). These four entry points are tightly bound to steps one through four, and the DSRM does not view steps five or six as offering an entry point to design science research (Peffers et al., 2007). This is debatable, for it seems conceivable that design research could be instigated by evaluation of an existing artifact which highlights flaws or potential improvements; it also seems likely that previously communicated research could spark ideas for new design science scholarship.

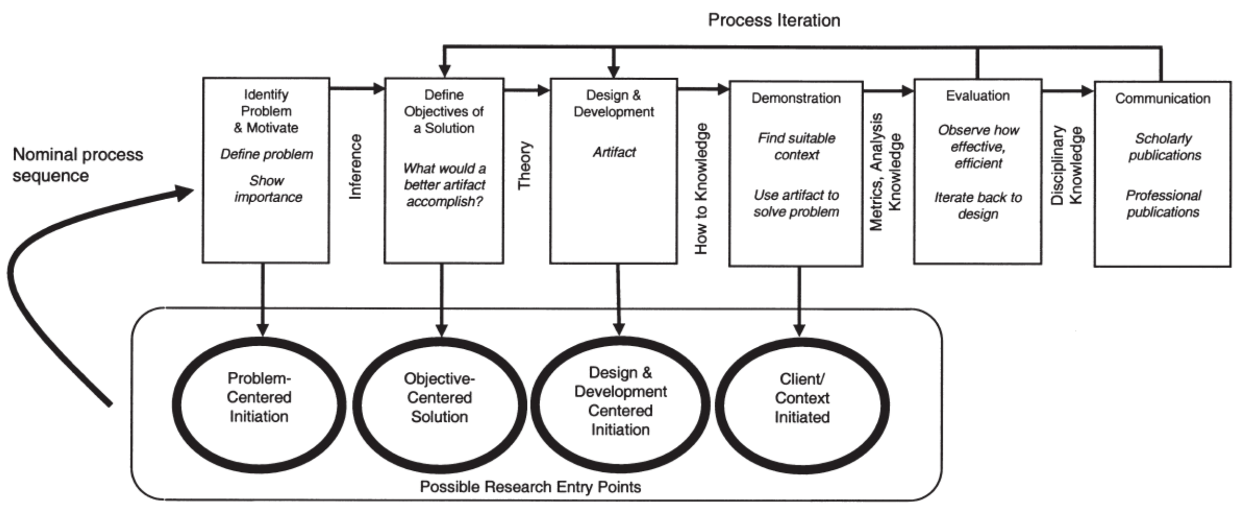

Figure 2.2. The design science research model (DSRM); from Ken Peffers, Tuure Tuunanen, Marcus A. Rothenberger, and Samir Chatterjee, "A Design Science Research Methodology for Information Systems Research," *Journal of Management Information Systems* 24(3) (Winter 2007-2008), 54. Copyright © 2008 by M.E. Sharpe, Inc. Used by permission.

The DSRM is preliminarily evaluated by showing how it is consistent with prior DS literature, theory, and practice, and by describing the process to be followed and the ways that it provides a mental model for research outputs. In addition, four case studies are described in the context of the DSRM to show how it functions in practice (Peffers et al., 2007).

4.1.3. Systems Development Research in IS

Nunamaker et al. (1990) develop their model of systems development research by first addressing the notions of "systems development" and "research in the social and behavioral sciences" separately. They describe systems development as consisting of five stages: 1) concept design, 2) constructing the architecture of the system, 3) prototyping, 4) product development, and 5) technology transfer. Concept design is the, "adaptation of technological and theoretical advances in potentially practical applications," (Nunamaker et al., 1990), while constructing architecture has to do with planning at multiple levels to design and plan the system to be built. Prototyping is viewed as the actual act of construction. Product development is a process of turning prototyped systems into commercial systems, while technology transfer has advances from the developed system filter back into society as a whole.

Nunamaker et al. (1990) describe social and behavioral science in six stages: 1) choosing a research problem, 2) stating hypotheses, 3) formulating the research design, 4) gathering data, 5) analyzing data, and 6) interpreting the results so as to test the hypotheses. This view of research, which is summarized as, "one forms a hypothesis and then attempts both to confirm and to generalize on the hypothesis through an analysis," (Nunamaker et al., 1990) is typical of more positivist communities of scholarship.

Nunamaker et al. (1990) have a linear view of both systems design and research methodology, which is no surprise; they are working from a conservative view of design, emphasizing very structured approaches to design which match structured research methodologies. Nunamaker et al. (1990) argue, as other design science scholars have, that design science is essentially a way of framing design as science. In the case of their model, analogues between design and research are sought, and design is recast as a research methodology: "Analysis may take forms as varied as formal proofs, developed systems, and opinion surveys. The results of the analysis become the argument (and evidence) in defense of the original hypothesis," (Nunamaker et al., 1990). Design science is a way of framing system design as a research analysis tool, and system development can be thought of as “proof-by-demonstration.” In addition, the IT artifact can become, “the focus of expanded and continuing research,” (Nunamaker et al., 1990).

Nunamaker et al.’s (1990) proposed process for systems development research in IS is as follows:

1. Construct a conceptual framework
2. Develop a system architecture
3. Analyze and design the system
4. Build the system
5. Experiment, observe, and evaluate the system

This model combines some of the steps from systems development with some of the steps from social and behavioral research. However, a notable limitation is step four, which seems to view the act of building as a thoughtless chore, necessary in order to reach step five, but in and of itself not very interesting. The “heavy lifting” of design has been done in steps two and three; the scholarly aspect of this model will take place in step five. This is typical of the conservative view of design, but contrasts starkly with the expert view (Lawson, 2004, 2005; Lawson & Dorst, 2009) or Fallman’s (2003) desire to draw upon aspects of the conservative, romantic, and pragmatic views. These perspectives, rather than viewing the building of a prototype as a mindless task to be executed from some master plan, see the building of systems as a form of “sketching” – a thoughtful process during which design assumptions are probed, considered, and altered.

Nunamaker et al. (1990) conclude by suggesting that, “Building a system in and of itself does not constitute research. The synthesis and expression of new technologies and new concepts in a tangible product, however, can act as both the fulfillment of the contributing basic research and as an impetus to continuing research. The important role played by systems development in the life cycle of complex research demonstrates its credibility as a research methodology."

4.1.4. Design Science as IS Action Research

Action research is an inductive approach to research where scholars study and intervene in local situations, improving those situations and examining the effects of their interventions for their impact. It bears a strong resemblance to participatory research (DeWalt & DeWalt, 2002). Some scholars argue that design science may be considered a form of action research, with an IT artifact substituting for other methods of intervention (Cole, Purao, Rossi, & Sein, 2005; Järvinen, 2007). This view is mildly controversial in the IS design science literature; some scholars agree that action research and design science are highly similar (Cole et al., 2005; Hevner, 2007; Järvinen, 2007) while others are less confident that this is so (Iivari & Venable, 2009; Peffers et al., 2007).

Järvinen (2007) examined the guidelines for successful action papers that were published in the *Management Information Science Quarterly (MISQ)* special issue on action research. These guidelines stated three requirements for acceptable action articles: 1) authors must demonstrate a contribution or potential contribution to practice (action), 2) authors must demonstrate a clear contribution to research (theory), and 3) authors must identify criteria by which to judge the research and show how it meets these criteria. To Järvinen (2007), these requirements seem closely related to those of a high quality design science publication.

In a careful, point-by-point comparison of action research to design science research, Järvinen (2007) found many similarities between the two, beginning with their intent to, "plan and take action in order to change a part of reality." On this point both action and design science research can be contrasted to natural science, which, "[tries] to understand reality," rather than shape it (Järvinen, 2007). Action and design science research were also similar in their emphasis on practical concerns in specific situations, their contribution to typical social or natural science goals, and their intent to take action and evaluate that action (Järvinen, 2007). Cole et al. (2005) came to similar conclusions in their cross-comparison of design science and action research approaches, saying, "Our analysis reveals that the two research approaches indeed share important assumptions regarding ontology, epistemology and more importantly, axiology."

Hevner (2007) also appears to agree with the assessment that design science and action research are related, saying, "The output from the design science research must be returned into the environment for study and evaluation in the application domain. The field study of the artifact can be executed by means of appropriate technology transfer methods such as action research." Peffers et al. (2007), on the other hand, point out that comparisons of design science to action research are viewed with varying degrees of favor by IS scholars: "DS research comes from a history of design as a component of engineering and computer science research, while action research originates from the concept of the researcher as an 'active participant' in solving practical problems in the course of studying them in organizational contexts. In DS research, design and the proof of its usefulness is the central component, whereas in action research, the focus of interest is the organizational context and the active search for problem solutions therein," (Peffers et al., 2007).

4.2. Artifacts as Theories and the Task-Artifact Cycle

In the HCI discipline, Carroll (Carroll, 1997) and several other scholars (Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll, Singley, & Rosson, 1992; Dillon, 1995) present a somewhat different view of design science from the IS view(s), where IT artifacts are valued as instantiated psychological theories. Like the IS perspective, this view of design science is informed by conservative perspectives on design. However, it more strongly emphasizes finished artifacts in addition to design processes and is also conceptualized within a discipline that – at least according to Carroll, et al. (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll et al., 1992; Dillon, 1995) – includes design as an essential component: "The field of HCI exists to provide an understanding of usability and of how to design usable computer artifacts. The actual conduct of HCI is circumscribed by the system development process, by the analysis of user needs and problems, and by the invention and evaluation of systems and applications to address these," (Carroll & Campbell, 1989). This is a relatively narrow view of HCI, omitting many modern variations. However, because design activity and designed IT artifacts are central to this definition, overall there is less need in the artifact-as-theory view of design science to seek justification for adapting design to scholarly purposes.

The artifact-as-theory view sees the HCI discipline predominantly as an applied research area of psychology, and Carroll and Campbell (1989) argue that, "the artifacts which HCI produces and evaluates necessarily incorporate psychological assumptions about their usability, about their suitability for the tasks that users want to do." IT artifacts that result from the HCI research process have "falsifiable empirical content," and, "support explanations of the form, 'this system feature has this consequence for usability,'" (Carroll & Campbell, 1989). In short, Carroll and Campbell (1989) argue that, "artifacts embody implicit theories of HCI. Although explicit theory is currently scarce in HCI, artifacts are abundant, and are fulfilling many of the functions that are conventionally associated with theories." This view is reflected by Dillon (1995), who draws upon Popper's (1996) notion of conjecture and refutation: "In the sense that design is problem solving, the artifacts that are created represent conjectures on the part of the design teams involved. That is, they are (on one level) the embodiments of theories about the users and the tasks they will be performing with the tool (artifact) being developed," (Dillon, 1995). Dillon (1995) is addressing an IS audience with this statement, and it is apparent that his views of design science are closer to the IS view than Carroll and Campbell's (Carroll & Campbell, 1989).

Carroll and Campbell (1989) suggest two possibilities for the claim that IT artifacts in HCI can be considered as theories: 1) a weak version, where HCI artifacts are a provisional medium for HCI until theory can catch up and 2) a strong version, where HCI artifacts are viewed as irreducible to standard scientific theories. In either case, the power of artifacts in HCI is as a stand-in or substitute for more typical theorizing as found in other disciplines. Unlike the IS view of design science, which sees theory as an important input to the design process (it is acknowledged to a lesser extent as an output), Carroll and Campbell (Carroll, 1997; Carroll & Campbell, 1989) view theory, in the form of instantiated IT artifacts, as the most meaningful output of a design process.

Carroll et al. (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll et al., 1992; Dillon, 1995) don't neglect design processes in favor of finished artifacts. An important contribution from the artifact-as-theory perspective is the notion of the task-artifact cycle (Carroll & Campbell, 1989; Carroll & Rosson, 1992). The task-artifact cycle suggests that HCI is a discipline in flux between understanding user needs and developing tools to address (and possibly modify) those needs. "People want to engage in certain tasks. In doing so, they make discoveries and incur problems; they experience insight and satisfaction, frustration and failure. Analysis of these tasks is the raw material for the invention of new tools, constrained by technological feasibility. New tools, in turn, alter the tasks for which they were designed, indeed alter the situations in which the tasks occur and even the conditions that cause people to want to engage in the tasks. This creates the need for further task analysis, and in time, for the design of further artifacts, and so on. HCI is the study of an ecology of tasks and artifacts," (Carroll & Campbell, 1989). Mackay and Fayard (1997) reflect and expand upon this view, positing that, "the interaction of people and technology is co-adaptive: people both adapt to the technology and they actively adapt it for their own purposes. Thus, the problem is not static: the 'same' technology is often very different in different environments." This perspective on HCI as a "user-centered" discipline, whether framed explicitly as a task-artifact cycle or more generically as user-centeredness in design has become virtually ubiquitous within the discipline, and its influence can be seen in many scholarly works by a great variety of authors (e.g. Abras et al., 2006; Benbasat, 2010; Nielsen, 1993; Norman, 2002, 2004a, 2004b, 2005, 2006, 2007; Norman & Draper, 1986; Robertson, Czerwinski, Fisher, & Lee, 2009; Shneiderman, 1998; Tory & Möller, 2004; Vredenburg et al., 2002; Williams, 2009; J. Zhang, Johnson, Malin, & Smith, 2002). The task-artifact cycle implies iteration as a core element of HCI scholarship, as designed artifacts are continually improved through empirical evaluation (the conservative view), inspired creativity (the romantic view), reflective analysis (the pragmatic view), or knowledge based on prior precedent (the expert view).

Emphasis on iteration and user-centeredness has also impacted the nature of system evaluation in HCI. Carroll (1997) argues that, "formal experiments are fine for determining which of two designs are better on a set of a priori dimensions, but they are neither flexible nor rich enough to guide continual redesign." This seems to be an acknowledgement that iteration in the task-artifact cycle is often less regimented than the conservative view of design suggests it should be (Fallman, 2003), and that such approaches may require different design and evaluation methods than those laid out in the conservative perspective. Nonetheless, like many HCI scholars, Carroll, Campbell, and Rosson (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992) still seem to implicitly adopt the conservative view that design should be rigorous, empirical, and scientific.

4.3. Design as a Coordinator of Scholarly Perspectives

Zimmerman, Forlizzi, and their colleagues (Forlizzi et al., 2008; Forlizzi et al., 2009; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman et al., 2010) depart from the view that design activity or design outcomes can be considered as equivalent to science. Rather, they define design thinking as a process that involves, 1) "grounding - investigation to gain multiple perspectives on a problem," 2) "ideation – generation of many possible different solutions," 3) "iteration – a cyclical process of refining concepts with increasing fidelity," and 4) "reflection," (Zimmerman et al., 2007). This seems to be an expression of the pragmatic view of design (Fallman, 2003), with its emphasis on reflective design activity. However, Zimmerman et al. (2007) also seem to adopt some elements of the romantic view, differentiating between "engineering design" and "creative design" (developers create software to a specification in engineering design, while designers continually reframe the problem and question underlying assumptions in creative design). They also define designers as those who have, "had training or extensive practical experience in a discipline such as architecture, product design, graphic design, or interaction design," hinting at elements of the expert view (Lawson, 2004, 2005; Lawson & Dorst, 2009). However, this definition emphasizes visual and physical media and makes little attempt to explain why some activities are design and others are not. It excludes a great many people who are considered as designers in the expert view of design: engineers, software developers, computer scientists, etc.

If the emphasis in the IS view of design science is on design processes and IT artifacts, the emphasis for Zimmerman, Forlizzi, and their colleagues (Forlizzi et al., 2008; Forlizzi et al., 2009; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman et al., 2010) is on designers themselves. Using an inductive approach, they interviewed HCI scholars and designers, using their discussions and observations to build a new model of what designers can contribute to HCI. In this effort, they also discovered a considerable limitation in current thinking about design in HCI: that many HCI researchers currently view design as focusing on surface structure and decoration (Forlizzi et al., 2008; Zimmerman et al., 2007). This creates situations where designers are brought into projects too late to have much input, their suggestions are frequently not adopted because the costs of implementing them are too high, and their input has virtually no relevance to research outcomes (Zimmerman et al., 2007).

Forlizzi et al. (2008) note five current approaches to including design activity in HCI research: 1) project research, 2) design methods research, 3) pattern languages, 4) critical design, and 5) research service. Project research is the research that designers do to inform a design, including user-centered activities like contextual inquiry and the development of personas or use cases. HCI researchers do not generally consider this kind of research to be a scholarly contribution; it is a way of informing design practice. Design methods research is about the, “development and evaluation of new design methods intended to improve the process of developing interactive products,” (Forlizzi et al., 2008). This is a very typical (and sometimes the only) way for designers to contribute to HCI, but it can be a narrow one; it limits designer contributions to strictly methodological research. Pattern languages are an emerging stream in HCI research, focusing on the common design patterns to be found within many software systems. This area of research is often approached as a design method. Critical design sees designers taking on the role of social critic: “design researchers engaged in critical design create artifacts intended to be carefully crafted questions. These artifacts stimulate discourse around a topic by challenging the status quo and by placing the design researcher in the role of a critic,” (Zimmerman et al., 2007). This approach is usually not widely accepted into the mainstream of HCI scholarship; when it is, it is usually framed as design methods research. Research service has designers, “working on research teams, engaging teammates in problem-framing exercises to help the team to both ground their research in terms of user needs and to frame the research around a preferred state it helps to achieve,” (Forlizzi et al., 2008). This usually involves the development of prototypes to communicate with various project stakeholders. However, this view of design contribution in HCI is more about fitting design practice into ongoing research projects, rather than letting designers drive research themselves.

For Zimmerman, Forlizzi, and their colleagues (Forlizzi et al., 2008; Forlizzi et al., 2009; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman et al., 2010), none of these ways of merging design and HCI scholarship are entirely satisfactory. All of them downplay designer knowledge and experience, possibly because many HCI scholars still view design as a "black art" rather than as an explicable series of "rational judgments" that can make real and meaningful contributions to research (Wolf et al., 2006). Accordingly, Zimmerman, Forlizzi, and Evenson (Forlizzi et al., 2008; Zimmerman et al., 2007) develop and present their own model of designer contributions to HCI scholarship.

4.3.1. A Model of Interaction Design Research in HCI

Like the various IS models of design science, the model of interaction design research in HCI sees researchers and designers grappling with "wicked" problems arising from, "groups of phenomena, rather than single phenomenon in isolation." These, "have too many dynamic and interconnected constraints to accurately model and control using the reductionist approach found in science and engineering," (Forlizzi et al., 2008). Unlike the IS models of design science, the model of interaction design research in HCI emphasizes the perspectives of various researchers, especially designers, but also engineers, anthropologists, and behavioral scientists. This model is less about design processes than it is about how different scholarly perspectives can both contribute to and benefit from research.

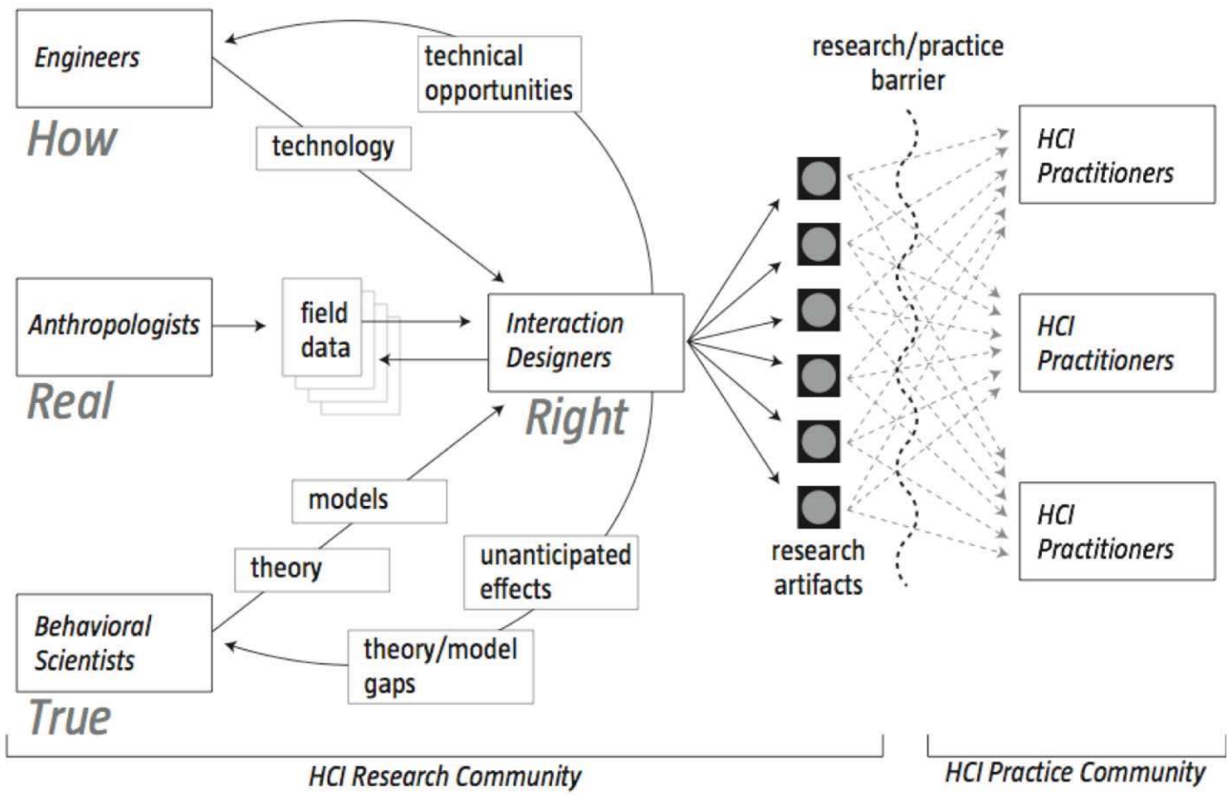

Figure 2.3. A model of interaction design research in HCI; from Forlizzi, J., Zimmerman, J., & Evenson, S. (2008). Crafting a Place for Interaction Design Research in HCI. *Design Issues*, 24(3), 19-29. Used by permission.

The model of interaction design research in HCI also expresses the relationship between four kinds of knowledge: 1) "how knowledge" (technical opportunities), 2) "real knowledge" (grounded explorations in the wild), 3) "true knowledge" (models or theories from science), and 4) "right knowledge" (artifacts that move the world from its current state to a preferred state) (Forlizzi et al., 2008). The notion of "right" knowledge is predicated on Cross's (1999) view that knowledge can reside within artifacts; this is similar to Carroll and Campbell's (1989) perspective that IT artifacts embody HCI theories, though the forms of knowledge assumed by these two views are very different. Cross (1999) suggests three aspects to designerly knowledge: personal, experiential "people" knowledge; tactical, strategic design "process" knowledge; and the embedded precedent of “product” knowledge. In his view, product knowledge is that which is contained within the artifact itself. Carroll and Campbell (1989), on the other hand, see the artifact as embodying a scientific conjecture about the state of the world that may be rejected (or not) during evaluation.

The model of interaction design research in HCI emphasizes four things on which design science should be evaluated, namely the design process (which must itself be reproducible, even if its results are not), invention (an artifact that is novel in some way), relevance (a demonstration that the artifact represents a preferred state and an explanation of why), and extensibility (whether or not the design research can be built upon) (Zimmerman et al., 2007). Because the model is predicated upon interviews and discussions with HCI scholars and designers, it also accommodates two values that these constituencies perceive in design: 1) designers bring a process for engaging massively under-constrained problems that are difficult for traditional engineering approaches to address, and 2) designers bring a process of integrating ideas from art, design, science, and engineering, in an attempt to make aesthetically functional interfaces (Zimmerman et al., 2007).

4.4. Prototyping as Inquiry

Fallman (2003) articulates a fourth view of design science: that design is a scholarly activity because it hinges upon sketching and prototyping activities as a method of inquiry. This view is reflected by Lawson (Lawson, 2004, 2005; Lawson & Dorst, 2009) and, to a lesser extent, Wolf et al. (2006), and is based on the notion that in HCI, prototyping activities are analogous to sketching in other design disciplines.

In this view, the act of sketching – on napkins, notebook paper, chalkboards, whiteboards, and countless other media – a seemingly simple activity, so common for designers, is in reality a complex way of design thinking (Fallman, 2003). "Right from the earliest stages of tackling a problem, designers' thinking is mediated by the sketches or visible notes that they make to familiarize themselves with the material they are manipulating," (Black, 1990). Lawson (2004, 2005) agrees, suggesting that, "Listening to conversation in (design) practices reveals just how extraordinarily efficient communication becomes, since enormously complex and sophisticated sets of ideas can be referred to using simple diagrams," (Lawson, 2004). Referring to this as "design drawing," Lawson argues that, "such a drawing is done by the designer not to communicate with others but rather as part of the very thinking process itself... parts of the proposed solution can be adjusted and the implications immediately investigated," (Lawson, 2005). Sketching is more than merely a process whereby the designer externalizes concepts or images that are held in the mind. The act of sketching allows the designer to grapple with visual representations, shape them, and "rephrase" them. Sketching is a middle ground between the designer's initial vision and the final, coherent whole. Sketching is the way that designers work and think; it is a method of inquiry (Black, 1990; Fallman, 2003; Lawson, 2004, 2005; Lawson & Dorst, 2009).

Fallman (2003) argues that prototyping activities are HCI's disciplinary analogue to sketching. Just as a sketch helps the designer in other disciplines to understand problems, contexts, and creative solutions, so prototyping helps the HCI scholar do likewise. Because prototyping is fundamental to HCI design, Fallman (2003) criticizes the way that design activities are so frequently deemphasized during traditional scholarly reporting (in journals, at conferences, etc.), instead of being acknowledged as a central aspect of the research activity and reported as such: "The act of actually bringing forth the prototype – the design process – seems often obliterated from descriptions of research projects; research prototypes just seem to 'happen.' ... The design process tends to remain implicit as researchers are embarrassed by not being able to show evidence of the same kind of control, structure, predictability, and rigorousness in doing design as they are able to show in other parts of their research."

5. Conclusion

It would be neat and tidy if the four views of design could be individually connected to one each of the four interpretations of design science. As the review of the literature shows, however, this is not the case. Rather, most writing on design science, especially in the IS field, is approached from the conservative view of design, which attempts to make design more like science by emphasizing structure and methodology in design activities. In this, the IS view of design science is rather coherent and well developed across a wide spectrum of literature, standing in sharp contrast to views of design science in HCI which are more varied (that is, individual authors adopt one of a variety of possible views) but also more accepting of other design perspectives. The pragmatic and expert views of design are more consistently represented in the HCI literature on design, though the conservative, engineering-oriented view is the most prevalent.

Cross (1999) helps to make sense of this mix of ideas, describing three kinds of knowledge: "things to know," "ways of knowing," and "ways of finding out." Each of these three kinds of knowledge will be different, depending on one's perspective as a natural scientist, an artist, or a designer. Fields of knowledge are the natural world for scientists, human experience for artists, and the artificial world for designers. Ways of knowing are rationality and objectivity for scientists, reflection and subjectivity for artists, and imagination and practicality for designers. Ways of finding out are experiment and analysis for scientists, criticism and evaluation for artists, and modeling and synthesis for designers (Cross, 1999). All of these forms of knowledge, ways of knowing, and approaches to inquiry are evident in the various perspectives on design and design science. The following table matches each of the four views of design science to their predominant (though not necessarily exclusive) things to know, ways of knowing, and ways of finding out using Cross's (1999) ontology as an organizing scheme:

	Design Science and Knowledge			
	Design Science in IS	**Artifact as Theory in HCI**	**Design as a Coordinator of Perspectives in HCI**	**Prototyping as Inquiry in HCI**
Design View	Conservative	Conservative	Pragmatic & Expert	Romantic, Pragmatic, & Expert
Thing to Know	*Designer:* - Artificial World	*Scientist:* - Natural World	*Scientist:* - Natural World *Designer:* - Artificial World	*Designer:* - Artificial World
Way of Knowing	*Scientist:* - Rationality - Objectivity	*Scientist:* - Rationality - Objectivity *Designer:* - Imagination - Practicality	*Scientist:* - Rationality - Objectivity *Designer:* - Imagination - Practicality	*Artist:* - Reflection - Subjectivity *Designer:* - Imagination - Practicality
Way of Finding Out	*Scientist:* - Experiment - Analysis *Designer:* - Modeling - Synthesis	*Scientist:* - Experiment - Analysis	*Scientist:* - Experiment - Analysis *Designer:* - Modeling - Synthesis	*Artist:* - Criticism - Evaluation *Designer:* - Modeling - Synthesis

Table 1.2. Design Science and Knowledge. A look at different perspectives on design science, the views of design they adopt, and their corresponding approach to knowledge.

The romantic view of design is the least represented among these various views for obvious reasons; a view of design as a "black box" that can't be explained or justified is difficult to usefully adopt into scientific modes of inquiry where explaining process is critical. It is less understandable, however, why the expert or pragmatic views of design are not more widely represented in these views of design science, particularly in the IS version which is the most formalized, most thoroughly conceptualized, and largest (by publication volume). After all, the expert view of design provides compelling ways that designers can reflect on their practice (in the manner of the pragmatic view), explain their process (similarly to the conservative view), and draw upon prior knowledge and precedent to produce designs that are both functional and artistic (as in the romantic view).

It is also notable that virtually none of these visions of design science are accompanied by statements for what is meant by design. Fallman (2003) and Zimmerman and Forlizzi et al., (Forlizzi et al., 2008; Zimmerman et al., 2007) make this effort in their discussions of sketching and designer vs. scholarly perspectives respectively; in most other design science writing, either HCI or IS, what is meant by "design" is left entirely to the reader to decipher from context clues and referenced literature.

The review of design and design science literature presented in this chapter draws attention to several gaps in the ongoing design science discourse. First, it is apparent that many scholars who are interested in design as it applies to research communities are talking past each other rather than to each other. It is especially notable that the IS vision of design science is built on literature that goes largely unnoticed by many in design-oriented areas of the HCI community, while much HCI design science writing is similarly uninteresting to those within IS. Several aspects of this phenomenon, particularly as it relates to the HCI community, will be explored in the next chapter: The "Pick Any Two" Problem. This upcoming chapter consists of an introductory section and the full text of a previously published paper on several disciplinary divides that inhibit HCI scholarship. Design science is proposed as a remedy to some of these divides, and three stages for design science – theory, design, and evaluation – are analyzed in the context of existing HCI scholarship. The upcoming chapter serves as a foundation for the theory, design, and evaluation (TDE) model for design science proposed in chapter four, and in many ways, the TDE model is designed to address the gaps in communication between HCI scholars in different communities.

It is also apparent from the review of the literature that an opportunity exists to rethink design science from a different design perspective than the conservative. In particular, the expert view of design (Boling, 2010; Christiaans & Venselaar, 2005; Cross, 1999, 2004, 1984; Cross et al., 1981; Gero, 1990; Lawson, 2004, 2005; Lawson & Dorst, 2009; Smith, 2010; Stolterman, 2008) addresses many of the critiques of the conservative, romantic, and pragmatic design perspectives. It is a perspective that has been developed from analysis of real-world design practice, through the study of expert designers and analysis of their work. It addresses critiques of the conservative perspective because it is based on the reality of what designers do. It is also a vision of design which matches well with scholarly points of view, which seek reliability and validity when reporting how knowledge has been gained. The expert view seems to reflect design activity in the HCI discipline, where HCI scholars and designers contend with design problems that are not always engineering-oriented in nature. Aesthetics, motivation, credibility, trust, and a variety of other topics interest HCI scholars, and these cannot always be explored through regimented and highly structured forms of design; organic, iterative, and creative approaches are often more suitable.

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CHAPTER 3, Part 1: Theory, Design, and Evaluation in the HCI Discipline

A previously published paper, *Theory, Design and Evaluation – (Don't Just) Pick Any Two* (Prestopnik, 2010), sets the stage for an upcoming conceptualization of the theory, design, and evaluation (TDE) model of design science. This paper is included in its entirety for its disciplinary perspective on design activities in HCI. Three distinct but iterative stages are proposed: theory, design, and evaluation. These stages are similar to the three cycles proposed by Hevner (2007); however, in Prestopnik (2010), the three stages are tied to the perspectives of the scholars who deploy them, with an argument that scholars from different backgrounds and traditions tend to emphasize different stages because of their unique points of view. Ultimately, *Theory, Design and Evaluation – (Don't Just) Pick any Two* contends that in HCI scholarship generally, and design science in particular, all three stages should be treated with equal merit.

The included paper includes an element of advocacy, suggesting that design science can be of great value to HCI scholars. This is not a unique suggestion, having also been made by Benbasat (2010) and Lyytinen (2010), whose "future directions of HCI in MIS" essays were the object of *Theory, Design and Evaluation – (Don't Just) Pick Any Two* as a response paper. Design approaches in HCI have also been advocated by a variety of others (e.g. Carroll, 1997; Carroll & Campbell, 1989; Carroll, Singley, & Rosson, 1992; Fallman, 2003; Forlizzi, Zimmerman, & Evenson, 2008; Forlizzi, Zimmerman, & Stolterman, 2009; Mackay & Fayard, 1997; Zimmerman & Forlizzi, 2008; Zimmerman, Forlizzi, & Evenson, 2007; Zimmerman, Stolterman, & Forlizzi, 2010).

Design science has the advantage of compelling scholars with a highly theoretical outlook to collaborate with designers who hold very pragmatic views of system development. Too often, systems are developed with little regard for theoretical grounding and contextualized, theory-driven evaluation. Then again, this problem can be reversed, producing scholarship that emphasizes theory but excludes the reality of the IT artifact itself. It has been noted that different HCI "camps" conduct inquiry into similar problems, but do not cross-communicate with each other very productively (Zhang & Dillon, 2003). Even within different HCI communities, scholarly interests and approaches can widely vary (Zhang & Li, 2005; Zhang, Li, Scialdone, & Carey, 2009). By considering theory, design, and evaluation as integral parts of a design science research agenda, HCI scholars from different traditions will come together, begin speaking each other's language, and produce work that is of interest to a broad cross-section of the scholarly and design communities.

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CHAPTER 3, Part 2: Theory, Design and Evaluation – (Don't Just) Pick Any Two

Prestopnik, Nathan R. (2010) "Theory, Design and Evaluation – (Don't Just) Pick any Two," *AIS Transactions on Human-Computer Interaction* (2) 4, pp. 167-177. [1]

Paper Abstract

The following discussion takes to heart Benbasat's (2010) and Lyytinen's (2010) suggestion that design science techniques should be more fully embraced by the HCI community. Design science approaches, which – in their ideal form – equally emphasize theory, design, and evaluation through an iterative design/research process (Amiel & Reeves, 2008; Hevner, March, Park, & Ram, 2004; March & Smith, 1995; Markus, Majchrzak, & Gasser, 2002; Wang & Hannafin, 2005), offer a comprehensive way to tackle many of the complex and sometimes highly subjective design-oriented research questions that are so familiar within the HCI discipline. In this response paper, three typical, high-quality HCI papers are examined in detail to explore the nature of the "pick any two" problem. Suggestions for how missing methodologies might be incorporated into these works through the design science approach are provided. Additionally, a brief review of HCI literature from three publication venues is conducted in order to roughly identify the extent of the "pick any two" problem. Several broad-based reasons for methodology omission are discussed, with suggestions for ways that these institutional challenges might be circumvented or overcome.

1. Introduction

There is an adage, well known within engineering and other practice-based communities, known as the project triangle (Gardiner & Stewart, 2000). The triangle speaks to the tradeoffs that factor into almost any project; it is usually presented as a balancing act among three equal components: cost, development time, and product quality. The adage goes something like this: "Good, fast and cheap – pick any two."

A variant on the project triangle comes to mind when reading Benbasat's (2010) and Lyytinen's (2010) interesting takes on future directions for HCI research. The modified saying might go something like this: "Theory, design, and evaluation – pick any two." This modified expression addresses the importance, noted by many authors (Ackerman, 2000; Benbasat, 2010; Dix, 2010; Grudin, 1994, 2006; Halverson, 2002; Kohavi, Henne, & Sommerfield, 2007; Lyytinen, 2010; Rogers, 2004; Shackel, 2009; Zhang et al., 2007), of at least one (and usually more than one) of the following methodological approaches:

- Application of Theory
- Design
- Evaluation

Importantly, this modified adage also implies a key weakness in much HCI literature - that any given study often gives advantage to two of the three methodological approaches while disadvantaging the third. It is surprising how many studies seem to adhere to the modified project triangle – theory, design, and evaluation – *pick any two*.

Many evaluative papers regularly offer only the briefest of theoretical sections (Dix, 2010). Research that does explore theory often leaves it unevaluated in the context of real-world systems and use settings (Rogers, 2004). Papers that do a good job with both theory and evaluation have a tendency to overlook design, offering theoretical explanations and results based on test instrumentation (i.e. existing websites, software, etc.) which are inadequate to answer the research questions or inapplicable to the world of practice. There are a multitude of reasons for these types of omission, and the following discussion is an attempt to highlight several of them, as well as to present potential solutions. The varying and sometimes limited technical skill-sets and abilities of HCI researchers, emphasis on journal-length publication in the field, grant and funding processes, and the rapid pace of technological development may all contribute to the "pick any two" problem. In addition, the fractured nature of the HCI research community, with various "camps" emphasizing different approaches, methodologies, and emphases, also appears to be a major contributor to this issue and a complex challenge to overcome.

The following discussion takes to heart Benbasat's (2010) and Lyytinen's (2010) suggestion that design science techniques should be more fully embraced by the HCI community. Design science approaches, which – in their ideal form – equally emphasize theory, design, and evaluation through an iterative design/research process (Amiel & Reeves, 2008; Hevner et al., 2004; March & Smith, 1995; Markus et al., 2002; Wang & Hannafin, 2005), offer a comprehensive way to tackle many of the complex and sometimes highly subjective design-oriented research questions that are so familiar within the HCI discipline.

In this response paper, three typical, high-quality HCI papers are examined in detail to explore the nature of the "pick any two" problem. Suggestions for how missing methodologies might be incorporated into these works through the design science approach are provided. Additionally, a brief review of HCI literature from three publication venues is conducted in order to roughly identify the extent of the "pick any two" problem.

Several broad-based reasons for methodology omission are discussed, with suggestions for ways that these institutional challenges might be circumvented or overcome. Most of these challenges can be reduced to a fundamental cause: the division of HCI scholarship into "camps" with varying philosophical and scientific emphases. Because the various HCI camps come from different traditions – HCI in MIS, engineering/computer science, and human factors – their approaches to research (and therefore, their methodological emphases) differ widely. The "pick any two" problem is ultimately used to explore this issue and frame potential solutions to the great challenge of more closely bonding the various "camps" of HCI.

In general, it is hoped that awareness of the "pick any two" problem will help HCI researchers find ways to diversify their approaches to HCI research, emphasizing theory, design, and evaluation more equally both across and within research projects, as well as helping to build bridges between HCI camps that emphasize differing research approaches, traditions, and philosophies.

2. Nature of the "Pick Any Two" Problem

A literature review of HCI research from varying perspectives and publication outlets was conducted (including conferences and journals with MIS, CHI, and Human Factors emphases), and three exemplar studies were selected for further detailed review. While of high quality, each study exemplifies a variant of the "pick any two" problem. The selected papers are not intended to be taken as empirical evidence of this phenomenon per se, but rather as case studies for the nature of the problem and as indicators that the "pick any two problem" is potentially real and worthy of further discussion.

2.1. Design and Evaluation

Cockburn and McKenzie (2001) presented an evaluation of an interface for organizing documents within a 3D space. Their research emphasizes design and evaluation to the disadvantage of theory, and is typical of many studies published within technically-minded venues (e.g. Denoue, Nelson, & Churchill, 2003; Funkhouser et al., 2003; Li & Hsu, 2004).

In their work, Cockburn and McKenzie (2001) briefly discussed technological advances in computing and graphics technology that have motivated their development and evaluation of a 3D document interface, without entering into a detailed discussion of user-oriented theories that would suggest such a design. They offered the following as justification for their research: “The three-dimensional (3D) graphics of computer games provide compelling evidence that desktop computers are capable of supporting rapidly interactive three-dimensional visualizations, yet 3D interfaces remain largely tied to niche markets such as Computer Aided Design,” (p. 1). While undeniably true, this justification offers no insight into the central research questions as stated by Cockburn and McKenzie (2001): “Firstly, what differences, if any, exist between the efficiency of working with 2D and 3D interfaces for document management? Secondly, what differences, if any, exist between people’s preferences for working with these interfaces?” (p. 1).

Arguing from system capability – that modern computers can support 3D, so therefore 3D should be used as a design technique – does not address the broad research questions, which are user (and not technology) oriented. At the conclusion of the study, the most definitive conclusion that can be drawn is that *the specifically evaluated* Data Mountain 3D interface (Robertson et al., 1998) was not more efficient than its 2D counterpart, but that it was preferred (Cockburn & McKenzie, 2001). Whether that finding is of use to others interested in 3D interfaces in general is debatable – it is probably useful to those developing an interface similar to Data Mountain, but perhaps less so to those developing other kinds of 3D interfaces. No real insight can be offered regarding 3D interfaces as a *class* of interface, because no attempt has been made to abstract and generalize findings through the framework of solidly researched and applied theory.

Theory is an important aspect of design science methods; as Hevner, March, Park, and Ram (2004) argue: “In both design science and behavioral science research, rigor is derived from the effective use of the knowledge base - theoretical foundations and research methodologies,” (p. 88). Additionally, as March and Smith (1995) argue, “…theories must explain how and why IT systems work within their operating environments,” (p. 255). Ideally, then, Cockburn and McKenzie (2001) would have used theory to argue in general terms why *any* 3D interface might be “better” than a 2D one. This could have covered affective or cognitive advantages of 3D over 2D, or elaborated on how users (Lamb & Kling, 2003) or context (Dourish, 2004) might play a role in efficiency or preference for 3D interfaces over 2D ones.

Furthermore, theory could have motivated the rest of Cockburn and McKenzie’s (2001) paper, suggesting a variety of useful research questions (e.g., What does theory say about how this should work? What experimental settings or survey questions will help us to evaluate whether the theory is supported? What are the most appropriate techniques for evaluating this interface and this theory?). Using theory to motivate the evaluation of a particular interface would also allow the researchers to report results in a context broader than just one specific system. In short, theory would make Cockburn and McKenzie's work more than, as Dix (2010) might argue, a usability study of just one particular 3D interface.

2.2. Theory and Design

Hong, Card and Chen (2006) studied a 3D concept designed to make online books more intuitive by simulating the turning of pages on real, physical books. Their research is an example of the de-emphasis of evaluation in favor of theoretical development and design (e.g. Cubaud, Thiria, & Topol, 1998; Dumas et al., 1999; Lee & Green, 2006; Marchionini, 2006; Stevens, Zeleznik, & Hughes, 1994).

Hong, et al. (2006) discussed the ongoing, theory-based debate over 2D versus 3D interfaces and the appropriate use of the book metaphor in an interface context. Though their theoretical development was short, it framed and underpinned their extensive design discussion, which covered topics such as geometric simulation for producing visually accurate page turns, implementation of high- and low-resolution page images, and the ability to "thumb" through pages at will to find content.

This paper's strength is its emphasis on linking simulation (the 3D book interface) to reality (real-world books that are familiar and comfortable to readers). The connection to physicality was made explicit, when Hong, et al. (2006) said, "As a visually enhanced object (Card, Mackinlay, & Shneiderman, 1999), a book metaphor taps into the user's familiarity with physical books. From the user's perspective, whether a book is a physical book or a virtual book being shown on a computer screen, 'turn to the picture in the middle of page 124' has the same meaning," (p. 1). Hong, et al. (2006) also argued for a specific page turning implementation using deforming cone geometry rather than cloth simulations.

Though this decision was a technical one, it was motivated by theory, in this case, an attempt to make the simulated book as close to physical reality as possible.

Hong, et al. (2006) omitted an evaluative component from their study. Their conclusion stated, “For a virtual 3D book, page turning is a fundamental feature and particularly important to convey the impression of reading or viewing an actual physical book,” (p. 7), but this was left untested. While earlier theoretical discussions suggest that this is so, Hong, et al. (2006) made no attempt to evaluate their finished product against other 3D book systems, 2D reading systems, or, for that matter, real, physical books.

According to Hevner et al. (2004), “Design-science researchers must constantly assess the appropriateness of their metrics, and the construction of effective metrics is an important part of design-science research,” (p. 88). Further, “Design science consists of two basic activities, build and evaluate,” (March & Smith, 1995 p. 254). In that tradition, this research could have concluded with an evaluative section to confirm the theoretical assumptions: that a book-like appearance and behavior will improve the user experience, that readers will enjoy a book-like presentation more than other types of screen-based reading, and that a simulated book will accurately reproduce the impression of reading a real book. By evaluating their prototype, Hong, et al. (2006) could have said something meaningful not only about the prototype itself, but about the theory upon which it was based. Instead, they proposed a design from theory and built it, but ultimately know little about its chances for adoption and success in the contexts for which they envision it.

2.3. Theory and Evaluation

Robins and Holmes (2008) discussed aesthetics and credibility in website design, providing a theoretical section and evaluative component. Study participants were asked to make credibility judgments about various "high aesthetic appeal" and "low aesthetic appeal" websites. Robins and Holmes omitted the third methodological approach, design, typifying what seems to be potentially the most common variant of the "pick any two" problem (e.g. De Wulf, Schillewaert, & Muylle, 2006; Hassenzahl, 2004; Kim, Lee, & Choi, 2003; Lindgaard, Fernandes, Dudek, & Brown, 2006; Spink & Saracevic, 1998; Tractinsky, Katz, & Ikar, 2000; van Schaik & Ling, 2009).

In their evaluation, Robins and Holmes (2008) found that sites with higher aesthetic appeal were seen as more credible by participants, an expected result. However, they also found an unexpectedly high standard deviation in credibility judgments which "indicate[d] that there was not a strong division in judgment between the high and low aesthetic stimuli," (p. 394).

This anomaly underscores methodological challenges in the way that high and low aesthetic appeal websites were selected (not designed) for evaluation. Robins and Holmes (2008) chose twenty-one web home pages to serve as stimuli in their experiment. Each home page as designed was considered to be the "high aesthetic appeal" case. To generate "low aesthetic appeal" versions of the stimuli, each of the twenty-one home pages was opened in an HTML editor and stripped of "visual enhancements".

The assumption that a web home page *as designed* must necessarily have high aesthetic appeal seems obviously false. Much research has been published looking at the phenomenon of web aesthetics (Hassenzahl, 2004; Kim et al., 2003; Nielsen, 1996; Norman, 2004; Tractinsky et al., 2000; van Schaik & Ling, 2009), a corpus which belies the simplistic, dichotomous nature of “aesthetic appeal” as used by Robins and Holmes (2008). To assume that because a page was *designed* it must therefore be *well* designed is to trust that the myriad developers involved in the twenty-one selected sites were all equally expert at their craft and all equally knowledgeable about what constitutes “high aesthetic appeal” and what does not. This is unlikely at best.

To create “low aesthetic appeal” websites by stripping designed websites of their visual enhancements is equally problematic. Robins and Holmes (2008) reported one site where the “low aesthetic appeal” version was much more highly rated than the high aesthetic appeal version. Robins and Holmes go so far as to suggest that the HTML stripping process may have improved the appearance of this particular home page.

A better test instrumentation for this study would potentially be to strictly control for aesthetic appeal by undertaking the kind of design science approach suggested by Benbasat (2010). Robins and Holmes (2008) might have draw from design and aesthetics literature or sought assistance from expert designers to generate controlled designs that achieve a consistent “high” or “low” aesthetic appeal. Furthermore, in the iterative tradition of design science (Hevner et al., 2004; Markus et al., 2002), it would make sense to repeat the design phase of this research using recurring evaluations to ensure that high and low aesthetic treatments were being produced as desired, and that credibility judgments remained consistent across design iterations.

Though more time-consuming than the method used by Robins and Holmes (2008), a design science approach would afford much greater experimental control, including the ability to focus on specific features of design (such as color, font style, layout, or imagery) as they relate to credibility within both high- and low-aesthetic appeal contexts. In addition, this would be more relevant to practice, since ongoing research could inform the development of aesthetic treatments (a practice-oriented operation), and adjustments to each aesthetic treatment would then be utilized within research.

3. Extent of the "Pick Any Two" Problem

From an analysis of individual papers, it is possible to ascertain much about the "pick any two" problem, but not to evaluate its extent within the overall HCI discipline. Accordingly, a brief heuristic review of papers from three HCI publication outlets was conducted. One hundred fourteen individual papers from the following three venues were reviewed and coded: Volume 68 of the *International Journal of Human-Computer Studies (IJHCS 2010)*, the 2007 *ACM Symposium on User Interface Software and Technology (UIST 2007)*, and the 2008 SIGHCI concentration of the *Americas Conference on Information Systems (AMCIS 2008).* Publication outlets were selected for their diversity of interests, topic areas, and approaches to HCI research, and individual papers from each publication were coded for their inclusion of each of the three methodologies in question: theory, design, and evaluation.

While design and evaluation sections were relatively easy to identify, what constituted a theory section was sometimes more difficult to ascertain. This was due to wide variations in the background material used to justify, support, and conceptualize research. Many papers, especially those in the engineering-oriented camps of HCI, emphasized technological innovation as justification for design or evaluative processes (e.g., computer speeds have improved, so this technology is now viable). These were typically not scored as including theory, unless they also included more meaningful discussions of human interactions with technology – *why* individuals might desire, adopt, or benefit from the technology under discussion, or *how* such interactions might be better described or explained by various concepts, constructs, and models. Since opinions on this matter vary, articles were coded conservatively; papers which included even very superficial theoretical sections were coded as including theory. Data collected during this review should be taken as an indicator of the "pick any two" problem, rather than as a comprehensive and authoritative picture of it. Nonetheless, evidence for the problem was found.

Of the 114 papers reviewed, 33.33% emphasized theory and evaluation while excluding design, 26.32% emphasized design and evaluation while excluding theory, and 6.14% emphasized theory and design while excluding evaluation. Of the reviewed papers, 24.56% emphasized all three areas equally, while 9.65% seemed to emphasize just one area.

Papers that emphasized theory and evaluation or design and evaluation were most common. This suggests that the majority of HCI researchers (understandably) place a high value on collecting and analyzing data, while having a more mixed attitude toward whether this analysis should be directed at theoretical constructs or technological artifacts. This split appears to be highly dependent on publication venue; journal articles were more likely to contain all three methodologies, while conference papers tended to include just two of the three.

Publications with an emphasis on theory and design to the exclusion of evaluation were more limited in their extent, comprising just 6.14% of the total. Of these publications, most were found within the more technically-minded *UIST 2007* conference proceedings. This seems to further validate the notion that most HCI researchers prefer to include some form of evaluation in their work. Nonetheless, enough theory-design papers were found in this short review to suggest that, while this aspect of the "pick any two" problem is more limited than its counterparts, it is still an omission in need of redress.

4. Causes of the "Pick Any Two" Problem

There are a variety of potential reasons that the "pick any two" problem may exist. Publication type and venue, researcher skill sets, grant and funding processes, and the rapid pace of technological development likely have their roles to play. More fundamentally, the division of HCI research into "camps" with differing approaches and background may be of greatest importance in driving this issue.

4.1. Publication Type

Journal-length articles were most likely to include all three core methodologies, with 38.18% of the *IJHCS 2010* articles containing all three. Nonetheless, 41.81% of the *IJHCS* articles emphasized only theory and evaluation, and 14.55% emphasized only design and evaluation. This suggests that while journal articles, because of their relative length and detail, may be better suited for research that encompasses theory, design, and evaluation, author choice still appears to have the determining role. It is also likely that some projects encompassing all three methodologies may not be suitable for even the relatively lengthy and detailed journal-style publication; some highly involved design research may, in fact, require more space to adequately describe problem spaces, theoretical background, design, technology, and the evaluation thereof.

Addressing the “pick any two” problem may require more than emphasizing the three core methodologies *within* papers. Emphasizing different aspects of research *across* several publications – including different disciplinary outlets – might also be beneficial. This would require more robust research plans so that relevant aspects of research reach the appropriate audiences and venues. Ideally, authors, publishers, editors, and reviewers would see individual publications within such research streams as mutually supporting; a publication emphasizing theory and design in one venue might cross-link or cross-reference a companion piece elsewhere containing an evaluative component. Currently, journals and conferences are not well-geared toward this model of publication, but such an arrangement would help authors and journals to improve the interrelatedness of varying publications coming out of the same or similar projects. Greater emphasis on other publication types might also make equal emphasis on theory, design, and evaluation more feasible. Currently, there is little emphasis on books and almost none on web-based publications within the HCI community, yet for some kinds of projects, book-length publications might be a useful way to cover a great deal of ground on a variety of project aspects. The World Wide Web, with its potential for multimedia display and interactivity, as well as virtually infinite publication space, could also become a unique way to publish a great deal of detail on theory, design, and evaluation with the added benefit of granting access to the designed artifact itself. This could also help to reach communities of practice more directly.

4.2. Researcher Skill-Sets

Another likely cause of the "pick any two" problem is the varying knowledge and technical skills researchers possess. It is uncommon to find researchers in any tradition, be it HCI in MIS, computer science, or engineering, who are highly proficient at all three of the methodologies under discussion. Those who are theory or evaluation-minded are unlikely to be adept at technical development, while those who design and build systems as part of research – often on tight schedules and in competition with others – may find detailed theoretical justifications for such development to be unnecessary or even counter-productive. As has been shown, a few are even content to propose and design from theory, but avoid scientific evaluation of what they have implemented. This suggests the need for better collaboration between HCI researchers and with others from outside the HCI community.

Large research programs and research partnerships, encompassing researchers with a variety of viewpoints and expertise, would help to strengthen research that might otherwise emphasize just one or two of the "pick any two" methodologies. Such collaborations can be challenging, as noted by Galison (1997). However, such collaborations have worked in the past through "trading zones," an approach whereby researchers from different domains negotiate for the specific needs of their domain until a satisfactory solution can be reached (Galison, 1997). In the HCI community, this might entail an engineering-minded researcher and a theory-minded researcher coming to an agreement over the relative emphasis for both the theoretical and design-based aspects of a particular research program. This is not compromising, but rather establishing a research plan that will be highly successful for both perspectives.

Complementary to collaboration, better design resources for non-technical researchers are also desirable. The phrase, “we’ll find some Master’s students to do it as part of a class project,” is commonly heard, but serious design-science requires developers who are experts, not students. Furthermore, these developers must thoroughly understand how design for research differs from commercial production. Training individuals for these seemingly disparate sets of skills and providing HCI researchers with better access to them is a challenging problem, with no obvious solution yet in sight.

4.3. Grants and Funding

The nature of funding within the HCI community is another potential point where one of the three “pick any two” methodologies can become deemphasized. Most funding agencies do not require or emphasize a holistic approach to research that might include theory, design and evaluation. This is exacerbated by the nature of the HCI proposal review process, which typically has funding proposals reviewed by engineering-focused or social-science focused reviewers, but usually not both. As an additional challenge, design science is a relatively new approach to the conduct of research, and is not yet widely acknowledged by funding agencies. While this situation is improving, with the NSF and others now occasionally requesting design-based proposals specifically, there is still space for more inclusion of design science approaches in the mainstream of the funding process.

4.4. Rapid Technological Development

The rapid pace of technological development is another potential culprit in the “pick any two” problem. The pace of technological change can be incredibly quick, and as a result, many HCI researchers, especially those with a design emphasis, find themselves working in newly conceptualized spaces. This creates challenges with respect to all three of the “pick any two” methodologies. In newly generated research spaces, theory is often limited or even non-existent, making it difficult to tackle design challenges without deemphasizing theory in favor of simply trying something new. Additionally, new research spaces come with extra challenges for design research, where technical problems to be solved may be non-trivial, requiring relatively more attention than other aspects of research. Finally, during evaluation, new and rapidly changing domains raise questions about what is important, what should be evaluated, and how such evaluations should be conducted. While individual researchers must weigh these various challenges for themselves, collaborative partnerships and a wider perspective on HCI research as a whole may help to produce more holistic approaches to “bleeding edge” research, even within tight deadlines and competitive research spaces.

4.5. HCI “Camps”

Publication type and venue, researcher skill sets, grant and funding processes, and the rapid pace of technological development are all potential causes for the “pick any two” problem, and each comes with a host of practical challenges and potential solutions. These difficulties appear to be traceable to a more fundamental issue, however: the division of HCI research into several uniquely different “camps.” Researchers from these camps typically disagree about the issues above – whether journal or conference publication is more valuable and useful to the discipline, what skill sets are necessary within HCI research, what funding agencies should look for in valid HCI research, and how rapidly evolving areas within the HCI domain should be studied. Camp differences and the reasons for them are likely the root cause for why the "pick any two" problem exists at all.

The HCI camps have been identified by Grudin (2005):

- Human Factors and Ergonomics
- HCI in MIS
- Computer-Human Interaction (CHI) and its Antecedents (such as CSCW)

The differences between HCI camps are historical and complex, but Grudin (2005, 2006) emphasized that the historical interest in mandatory computer use vs. discretionary computer use, different theoretical foundations between camps, and differences in research and disciplinary foci are potential reasons why HCI researchers remain divided.

The CHI and human factors camps trace their lineage to engineering-oriented disciplines such as computer science, ergonomics, and aeronautical engineering. It is therefore unsurprising to see research from these camps emphasizing the design and evaluation of technical systems; such methodologies are the lifeblood of engineers and engineering-minded scholars. The HCI in MIS camp has a background oriented around mandatory-use, organizational applications (2005, 2006) and is further steeped in a social science, rather than an engineering, tradition. Rather than emphasizing specific technical solutions geared toward the individual, therefore, HCI in MIS researchers seem to gravitate toward broad, socially or organizationally-oriented theories with wide applicability in a variety of use contexts. This is supported by the previously described review of publications, which showed that publishing outlets favored by HCI in MIS researchers (*SIGHCI-AMCIS 2009* and *IJHCS 2010*) heavily emphasized theory and evaluation, while the outlet favored by engineering and computer science-minded researchers (*UIST 2007*) heavily emphasized design and evaluation.

The HCI camps may further be described in terms of "prescriptive" and "descriptive" science (March & Smith, 1995). Prescriptive science is aimed at "improving IT performance," (March & Smith, 1995) and appears to be the basis of the design and evaluate model found within CHI and the other technically-minded camps. Descriptive research, on the other hand, "…aims at understanding the nature of IT. It is a knowledge-producing activity corresponding to natural science," (March & Smith, 1995 p. 252). The HCI in MIS camp seems most comfortable with seeking understanding through theory and evaluation, rather than through a process that emphasizes building and testing. Though most HCI in MIS researchers have a social science rather than a natural science mindset, their desire to explain human phenomena in the context of computational systems is more akin to the natural science researcher, who desires to explain natural phenomena in the world, than the computer scientist or engineer, who desires to design and build new technological artifacts. Therefore, it seems likely that the "pick any two" problem, which sees different researches emphasizing different methodological approaches, may ultimately stem from methodological and philosophical distinctions between HCI camps.

HCI Camps & Methods			
HCI Camp	**Scientific Philosophy**	**Domain Emphasis**	**Resulting Methods**
HCI in MIS	Descriptive: Social Science	Business & Organizational Computing	Theory & Evaluation
Computer-Human Interaction	Prescriptive: Computer Science	Discretionary Computing; Personal Computing	Design & Evaluation or Theory & Design
Human Factors & Ergonomics	Prescriptive: Engineering	Physical Interface; Human Factors	Design & Evaluation or Theory & Design

Table 3.1. HCI camps, their scientific philosophy/orientations, domain emphases, and resulting methodological approaches

Many have suggested that the various camps of HCI should work together, arguing that mutual conferences, joint publication venues, and other “mandated” methods of unification are the answer to bridging the gap. While such collaboration may seem ideal, it has not worked well in the past (Grudin, 2005, 2006). Too many small but important differences exist; for example emphasis on journal vs. conference publication, different uses of terminology, and different methodological groundings have all resulted in a lack of cohesiveness in HCI.

These are sharp divisions which are not easily overcome, and it may be that "top-down," mandated approaches to unifying the camps are not the solution, if indeed a solution is even needed. There is much to be said for a research community that encompasses a variety of theoretical and methodological traditions, at least when those traditions are complementary. Forcing the camps of HCI into a unified whole without due consideration for their individual uniqueness may not turn out to be an overall improvement of the discipline.

On the other hand, the desire for a more cohesive HCI research community, as expressed by many (Dix, 2010; Grudin, 1994, 2005, 2006; Halverson, 2002), is non-trivial, stemming from a desire to see each camp's work more strongly influence and improve the others. In a sense, the desire for camp unification may at its root be a desire for methodological completeness – an interest in seeing the "pick any two" problem conquered through better coordination amongst the camps of HCI.

5. Picking All Three

It was suggested earlier that design science, with its equal emphasis on theory, iterative design, and evaluation (Hevner et al., 2004; March & Smith, 1995; Markus et al., 2002), is a candidate for solving the "pick any two" problem. If that problem is symptomatic of something larger – the camp divisions in HCI – perhaps the design science solution is equally applicable to this larger issue.

Rather than attempting to mandate or otherwise force mutual HCI conferences, publication outlets, or interest areas, a less disruptive solution to the fracturing of the HCI discipline may be to encourage the use of design science methods wherever they may be useful. It is suggested here that, instead of picking "any two" of three key methodologies (in practice, the approaches that one's own camp is most comfortable with), why not try to include all three? This has the challenge – but also the potential advantage – of forcing HCI researchers out of their comfort zones and into new, mutually informative areas. For those in a technical, engineering-oriented camp, a new emphasis on theory will render their design-oriented studies more approachable to researchers with a "descriptive science" mindset. For those in HCI in MIS, a fresh emphasis on design may create inroads to those who already exist comfortably in those domains – computer science and CHI scholars, as well as HCI practitioners. This would also motivate HCI researchers across all camps to find and be informed by studies conducted in areas in which their own camp is not traditionally strong.

Many challenges, tradeoffs, and caveats accompany this suggestion. Too much emphasis on design research could have the unintended consequence of shifting the focus of HCI scholarship away from human problems and toward artifacts for their own sake. Well-planned design science studies should have the opposite effect, encouraging researchers to understand both human and technological problems simultaneously, but in any design project, there is a risk that the difficulties of implementation may come to overshadow other research considerations. It is also wise to remember that not all research questions will be well served by a dogmatic design-based approach. While it is suggested that greater emphasis on design science research will benefit HCI scholarship, it is also acknowledged that different problems require different solutions; HCI research should remain flexible in its approach to problems that involve human-computer interactions. Finally, design science can also be time-consuming, requiring more effort for the same scholarly impact of more traditional research approaches. Nonetheless, by focusing attention on theory, design, and evaluation, researchers may find that they produce more holistic research and, in so doing, create a more unified HCI discipline.

6. Conclusion

Three methodological elements – theory, design, and evaluation – found within “typical” HCI evaluation studies were discussed in light of the project triangle, an adage which suggests that (as in the case of cost, time, and quality) only two of the three will be optimized at any one time. A detailed examination of three exemplar papers was conducted, followed by a brief review of 114 papers from three different HCI publication outlets. In both reviews, evidence was found for the “pick any two” problem, and its nature and extent were described.

Several potential reasons for the “pick any two” problem were discussed, including publication type, researcher skill sets, funding procedures, and the rapid pace of technological development within the HCI domain. Several practical suggestions for avoiding or overcoming these challenges were given, but each was also reduced to the more fundamental level of HCI “camp” divisions. It was noted that the theoretical and methodological traditions of each camp tend to influence which methodological approaches are used and which are avoided by various researchers.

Design-based approaches to research, which equally emphasize all three methodological components, were proposed as one way to overcome methodological omission. Both Lyytinen (2010) and Benbasat (2010) have suggested that HCI researchers should more fully embrace design science approaches in their research, with Lyytinen (2010) suggesting that this will, “improve ecological validity of [HCI scholar’s] studies and also to develop ways to integrate HCI knowledge and theory to effective design interventions,” (p. 24). Benbasat (2010) further argues that, “…to be interesting and relevant (to practice), research in HCI should have a design component coupled with an evaluation of this design,” (p. 16).

Design science is, in many ways, the bridge between pure theory, the value of which is not always apparent to the technically-minded, pure technical development, the value of which is not always apparent to those with a theoretical mindset, and evaluation, the value of which, while acknowledged by most researchers, is highly dependent on *both* theory and design. Design science approaches would have the dual benefit of improving the methodological quality of some types of HCI research, while also forging closer ties between the various HCI camps.

Ultimately, the adage, "Theory, design, and evaluation – pick any two," should not be a guiding force for HCI research in the future; often, each of these methodological components has an important role to play. Greater effort to capitalize on each of them via a design science approach to research, if thoughtfully and appropriately done, will have the result of improving scholarly research and bridging gaps within the HCI discipline.

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CHAPTER 4: The Theory, Design and Evaluation (TDE) Model

1. Justification

Lawson (2005) points out a clear challenge with bringing design and scholarship together: "Social science remains largely descriptive, while design is necessarily prescriptive, so the psychologists and sociologists have gone on researching and the designers designing, and they are yet to re-educate each other into more genuinely collaborative roles." Despite the array of good thinking on design science that exists in HCI, IS, and other disciplines, there is not yet a preferred approach for how design and science can be productively joined (Forlizzi, Zimmerman, & Evenson, 2008). A warning offered by Peffers et al. (2007) is pertinent: "Without a framework that is shared by authors, reviewers, and editors, [design science] research runs the danger of being mistaken for poor-quality empirical research or for practice case study."

There is an obvious desire in various branches of the HCI community to undertake more than just scholarly activity. Shneiderman (2006) nicely summarizes this in his foreword to *Human-Computer Interaction and Management Information Systems: Foundations* (Zhang & Galletta, 2006): "I recognize a devotion to societal concerns for how information and communication technologies are applied in the workplace. These authors want to be more than respected academics; they aspire to creating a better world."

In the face of these concerns and desires, it is worthwhile to explore structures that can support harmonious cooperation between designers and scientists. In this chapter, concepts from existing design science models, elements developed out of the work presented in chapter three, and ideas developed over the course of several design science projects (see chapters 6, 7, 8 and 9) are synthesized into one such possibility – a new model for design science: the theory, design, and evaluation (TDE) model.

Many existing models of design science, especially those from IS (e.g. Hevner, 2007; Hevner, March, Park, & Ram, 2004; Järvinen, 2007; Nunamaker, Chen, & Purdin, 1990; Peffers et al., 2007) frame design as a scientific methodology – that is, as science in and of itself – when structured properly and enacted under the right conditions. Variations on this perspective are held by those in the HCI community as well (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll, Singley, & Rosson, 1992; Dillon, 1995). In general, there is a desire in many design-oriented academic disciplines such as HCI and IS to "elevate" design to the level of science, making knowledge generation through design palatable to academic peers who are not always sanguine about its scientific merit or scholarly benefit.

The theory, design, and evaluation (TDE) model is a departure from this inclination. Design is specifically *not* argued to use the same methods or produce the same outcomes as scientific inquiry, and there is subsequently no pressing need to elevate design to the level of science. Indeed, it seems strange to imply that science is somehow above or better than design; the TDE model simply accepts these as two different things with different but complementary perspectives and goals. Design, as suggested by a variety of scholars (e.g. Gregory, 1967; Hevner, 2007; Hevner et al., 2004; Mackay & Fayard, 1997; March & Smith, 1995; Zimmerman, Forlizzi, & Evenson, 2007), is principally about changing the world from its current state to a preferred state; it is about inventing things and solving problems.

Science, on the other hand, is about explanation and prediction; it is about understanding reality (Hevner et al., 2004; March & Smith, 1995; Simon, 1996).

Current topics of interest in HCI include many that could be productively explored through design activity (attitude, learning, motivation, behavior, cognitive beliefs, emotion, performance, trust, ethics, etc.), as well as many that by their nature must directly involve design (development methods and tools, software and hardware development and evaluation, user interface design, etc.) (Zhang & Li, 2005; Zhang, Li, Scialdone, & Carey, 2009). The TDE model is envisioned as a way to explore any of these varied interests in conjunction with design. Accordingly, design science projects following the TDE model produce both scientific and design outcomes: 1) IT artifacts that address real design problems and also 2) serve as vehicles for scholarly natural or social-psychological research around some phenomenon of interest. These mutual design and scholarly outcomes are strongly tied to one another; the design and evaluation of IT artifacts will support scholarly activities just as scholarly activities will greatly influence design. Designing and evaluating IT artifacts in the TDE model achieves one of the key goals found in virtually all models of design science: “knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artifact,” (Hevner et al., 2004). At the same time, because the TDE model produces both design and science outputs, Peffers et al’s. (2007) warning is also addressed. Scholars involved in a TDE design science project will ask natural science or social-psychological research questions and then leverage the IT artifact and its evaluation both during and after design as tools address them in an empirical fashion.

The TDE model adopts the expert view of design, where designers operate from experience using their formal design training, prior design precedent, examples, techniques, tricks, strategies, and an ability to creatively synthesize these into innovative design solutions (e.g. Boling, 2010; Christiaans & Venselaar, 2005; Cross, 1999, 2004, 1984; Cross, Naughton, & Walker, 1981; Gero, 1990; Lawson, 2004, 2005; Lawson & Dorst, 2009; Smith, 2010; Stolterman, 2008). This is an important difference between the TDE model and other design science models. Other models (especially in IS) tend to view design in the more conservative and structured manner described by Fallman (2003), despite many criticisms of this perspective (Alexander, 1971; Brooks, 1975/1995; Carroll, 1997; Carroll & Campbell, 1989; Cross et al., 1981; Dillon, 1995; Ehn, 1988; Fallman, 2003; Lawson, 2005; Stolterman, 2008). Few of those writing on design science explicitly adopt the expert view of design, despite it being built upon years of cognitive research on design activity and designers (Akin, 1986; Darke, 1979; Eastman, 1970; Hillier, Musgrove, & O'Sullivan, 1972; Lawson, 1979, 2004, 2005; Lawson & Dorst, 2009; Rowe, 1987).

However, the expert view of design overcomes many of the limitations imposed by the conservative and other design perspectives, particularly because it is based upon close study of what designers actually do when they are designing. The expert view connects design practice to cognition and memory. It is structured around the notion that design activities are built upon a vast accretion of learned knowledge. In contrast to the romantic view, an expert designer, given the opportunity, should be able to explain what reference materials influenced his or her design decisions why. There are many ways to record a design process, reflect upon it, and learn from it, including journaling, note taking, audio or video recording, keeping photographic records, regular interviews, etc. Smith (2010) suggests the mechanism of "audit trails," arguing that, "the researcher can produce and maintain a record of the resources, processes, and decisions involved in the development of a case for possible review in the form of peer debriefing or member checking." Many of these approaches mirror well-understood and commonly accepted methodologies for data collection in research, and many are well-suited for scholarly analysis, interpretation, and augmentation using methodologies like content analysis, interviews, observations, think-aloud sessions, case studies, expert reviews, or surveys (Babbie, 2010; Boyatzis, 1998; Creswell, 2009; Duchowski, 2007; Emerson, Fretz, & Shaw, 1995; Richey & Klein, 2007; van Someren, Barnard, & Sandberg, 1994; Weber, 1990; Yin, 2009).

The expert view of design, like Fallman's (2003) pragmatic view, acknowledges the situatedness of design activities, but also provides a path toward generalizable knowledge. Every design problem is different in its details, and some are extraordinarily difficult. Most, however, are not absolutely unique. Virtually all design problems come out of previous challenges and their solutions. They often contain elements that have been addressed (either successfully or not) in prior work. By emphasizing precedent and a ready repertoire of design techniques, the expert view creates a path to apply past knowledge to challenging design problems (Lawson, 2004, 2005; Lawson & Dorst, 2009). Furthermore, when difficult problems are finally addressed, the resulting designs (whether they succeed or fail) become precedent themselves, a tool for future designers addressing future problems. In a sense, an accumulated reservoir of design precedent is to the expert designer what a scholarly corpus is to the HCI researcher: an immense pool of accumulated information from which ideas and inspiration are drawn and to which new knowledge is periodically contributed.

2. Overview of the TDE Model

The following is a visual representation of the TDE model, a construct diagram showing its various component elements and the ways they relate to each other. In this chapter the TDE model is described and discussed in terms of these constructs and the processes by which they are connected.

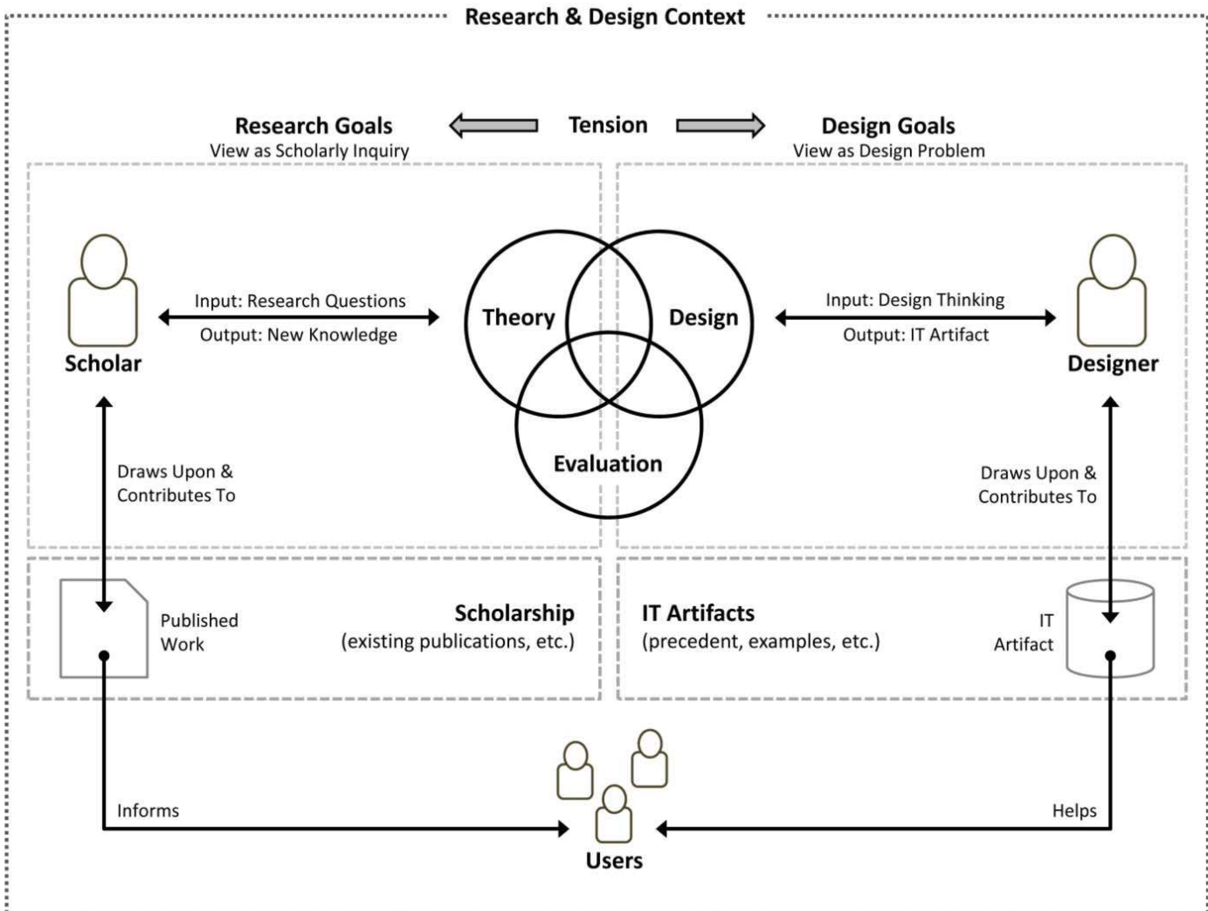

Figure 4.1. The TDE model showing parallel design and scholarly activities.

In the TDE model, design and scholarly activities complement and inform each other when they are embedded into a defined context and undertaken in parallel across three iterative stages: theory, design, and evaluation. During the TDE design science process, scholars and designers draw upon prior work from their own respective fields (peer reviewed research in the case of scholars, prior design precedent in the case of designers) but engage with the parallel field as well. Scholars and designers also contribute together back to each corpus of work by producing new scholarly publications and one or more IT artifacts in collaboration. Different user constituencies that exist both within and outside of the scholarly and design communities will find various TDE contributions valuable for different reasons.

Note that there is an inherent tension in the TDE model as designers will usually tend to make activities more like design practice, and researchers will tend to make them more like traditional scientific scholarship. Designers and researchers using the TDE approach must be mindful that design goals and research goals can sometimes compete or conflict with each other. Still, there is great benefit to bringing both scholarly and designer perspectives to bear on a research and design project, where insights from both mindsets can contribute to compelling research findings and highly innovative and useful IT artifacts.

In the next sections, the following elements of the TDE model are addressed in detail:

1. The Periphery (design context)
2. The Partnership (scholars, designers, users, and domain experts)
3. The Core (theory, design, and evaluation; their iterations and variations)
4. The Outcomes (IT artifacts, new knowledge, and the dissemination of both)
5. Tension (conflicting scholar and designer perspectives; overall project feasibility)

3. The Periphery: Context

Context is the situation or environment into which the designed IT artifact will be introduced and within which research questions will be posed and hypotheses tested. This is similar to the “environment” cycle in Hevner’s (2007) three cycle model for design science. In IS, context is almost always assumed to be organizational rather than explicitly stated (e.g. Hevner et al., 2004). Yet design-oriented scholars in the HCI discipline and outside it frequently point out the importance of exploring many different contexts (e.g. Dourish, 2004; Nardi, 1996; Sandoval & Bell, 2004; van Schaik & Ling, 2009). HCI scholars are increasingly interested in non-organizational settings like social media, education, social computational systems, collective intelligence, the mobile environment, mass markets, augmented reality, assistive technologies, gaming, personal computing, etc.

In the TDE model, scholars and designers must establish context early. Designers need to clearly understand context so that they may attend to important elements of the design environment, undertaking what Zimmerman et al. (2007) refer to as the, “upfront research practitioners do to ground, inform, and inspire their product development.” Establishing context creates a starting point for this kind of background research, from which use scenarios, user groups, sub-contexts, and related contexts may be identified. Importantly, an established context also helps the designer to narrow his or her repertoire of techniques and precedent to those which are most relevant to the ongoing project.

A clearly defined context helps scholars to narrow and familiarize themselves with literature and thinking that are relevant to the research questions, hypotheses, and – eventually – evaluation methods of interest. A well-understood context also places limits on the scope of research and resulting knowledge claims and ensures that scholarly results are connected to realistic use scenarios. Ultimately, selecting, defining, and thoroughly understanding context makes certain that the most critical question – “so what?” – will be answerable by both designers and scholars.

4. The Partnership: Scholars, Designers, Users, & Domain Experts

4.1. Scholars, Designers & Users

In the TDE model, design and science are treated as two semi-separated but nonetheless complementary processes. When enacted as a balanced pair, design and science together have the potential to produce wide ranging results that are of value to many different constituencies. Designers who participate in a TDE research project are expected to address compelling and interesting design problems through their typical design practice. Similarly, scholars are expected to produce natural/social-psychological research, much as they would in a traditional research study: research questions are to be asked, hypotheses proposed and tested, data collected, and analysis undertaken. However, both design and science activities are to be undertaken in parity, informing each other and expanding the potential contributions of each.

In parallel to design efforts, natural science and social-psychological research activities are directed toward research questions that interest several different groups: 1) scholars, whose ultimate purpose is to generate new knowledge, 2) designers, because addressing research questions may generate new insights into the design space, and 3) various users of the IT artifact, because addressing research questions may concretely improve the context toward which the project is targeted. Similarly, in parallel to scholarly activities, design efforts are directed toward the development of IT artifacts that will interest the same: 1) scholars, because the IT artifact will enable them to address their research questions, 2) designers, because the design problem and its potential solutions are compelling, interesting, and valuable, and 3) users, because the IT artifact will improve their lives in some meaningful way. By undertaking scientific discovery and design activity in parallel, scholarly findings can immediately be explored for their practical implications even as design activities and the use of the artifact itself can become valuable sources of data and insight for research. While the IT artifact should be interesting to scholars, it is especially valuable to designers as a contribution to prior precedent – an example of techniques and approaches applied within a specified design space. While scholarly results (i.e. data, analysis, theory, and – ultimately – scientific research papers) should be interesting to designers, these are especially valuable to scholars as a contribution to the existing scientific literature within one or more fields.

Design efforts may frequently address "wicked" design problems (Brooks, 1987, 1996; Rittel & Webber, 1984), but in the TDE model, unlike some other models of design science (Hevner, 2007; Hevner et al., 2004; Järvinen, 2007; Nunamaker et al., 1990; Peffers et al., 2007) this is not mandatory. A successful TDE research project could produce a relatively mundane IT artifact but use it to explore novel, interesting, or controversial research questions. Or, it might direct a set of relatively common research questions toward an extremely unique or innovative IT artifact developed to address a challenging "wicked" problem. Of course, it is also possible to direct novel research questions toward an innovative IT artifact (an ideal circumstance), and it may even be useful to ask relatively typical research questions about a mundane artifact that has been deployed in a unique, interesting, or under-studied context. In all these cases, the TDE model for design science can produce outcomes that are of value to designers and scholars, as well as to the end users of their combined effort.

In the expert view of design (e.g. Boling, 2010; Christiaans & Venselaar, 2005; Cross, 1999, 2004, 1984; Cross et al., 1981; Gero, 1990; Lawson, 2004, 2005; Lawson & Dorst, 2009; Smith, 2010; Stolterman, 2008), design processes are explicable; when designers think about their process carefully, they are able to articulate it in great detail (Wolf, Rode, Sussman, & Kellogg, 2006). This is especially so when care is taken during design to note why and how design judgments are being made. In the TDE model, the act of design documentation and explication is critical. Design is neither a process which scholars must tolerate until scholarly activity can begin nor a "black art" that somehow corrupts the scientific research process (Forlizzi et al., 2008); rather, when coupled with inductive or deductive research activity, design can become a powerful vehicle for producing valid and reliable findings. As designers grapple with a problem and explore its many features and complexities, their insights and attempted solutions, whether successful or not, become a source of data – the underpinnings that help to make sense of later results.

At the same time, Lawson (2005) notes, "we must not expect the design process to be as clear, logical, and open a process as the scientific method. Design is a messy kind of business that involves making value judgments between alternatives that may each offer some advantages and disadvantages." In the TDE model, scholars and designers each must bend a little to the requirements and perspectives of their counterparts. Designers unused to explicating their process so thoroughly may become frustrated at scientific requirements of rigor, validity, and reliability, but these are necessary to produce good scholarly outcomes. Scientists may worry that design processes seem unscientific – a designer who cannot fully articulate his or her decision-making does indeed seem to turn design into a "black art." Scientists must be willing to elicit information from their designer colleagues, and designers must be willing to reciprocate by providing said information. Scholars and designers who act in isolation, even around the same set of problems and questions, cannot be said to truly be doing design science as it is envisioned by the TDE model.

Note that while the scholar and designer are visualized as separate entities in the overview diagram in section two, it is possible – and occasionally desirable – that the scholar and designer mindsets reside within the same person. This creates special forms of tension, as a single individual must be alert to the unique demands of scholarly and scientific activities, as well as vigilant with respect to his or her biases in favor of one or the other. However, the designer-researcher (or, depending on one's partiality, the researcher-designer) is also in an enviable position, able to perceive the entirety of the design science effort and nimbly shift perspectives and activities as different stages of work are entered and departed. Like an expert designer (or, for that matter, an expert scholar), the designer-researcher may be highly individualistic, but his or her experience in conducting design and scholarly activities simultaneously can be tremendously valuable.

4.2. Domain Experts

Domain experts (also sometimes referred to as subject-matter experts or SMEs) are partners in the research effort, but not in a primary role of either designer or scholar.

Rather, they are individuals recruited from the identified design and research context who have an interest (or at least willingness) to facilitate research and design efforts. Because the domain expert works directly in the context of interest, he or she is able to provide deep insight that can be highly valuable to both scholars and designers. Examples might include individuals who will become eventual end users of the designed IT artifact, managers, scholars from other fields, educators, marketers, or technicians. It is often desirable to recruit more than one domain expert to obtain a range of perspectives. For example, in a project about visualization technologies in the history classroom, domain experts might include experienced history instructors, academic IT staff, college administrators, and students, depending on the scope and focus of the design and research effort. In one sense domain experts are clients – the IT artifact itself may be a system they expect and hope to use when it is finished. However, domain experts who are more deeply involved and have a broad understanding of research goals can also act as true partners to the design science process and may provide more meaningful insights than those who are treated as simply a source of data.

5. The Core: Theory, Design, and Evaluation

In *Theory, Design and Evaluation – (Don't Just) Pick Any Two* (Prestopnik, 2010), three eponymous interrelated stages for HCI research were discussed and described. These three stages form the core of the TDE model for design science. In iterative fashion, design science can begin or end with any of the three. Indeed, it can be difficult to precisely pinpoint the beginning or end of design science activity, so the TDE model avoids delineating start and finish too narrowly. Some design science efforts may gradually grow out of more traditional research projects or design initiatives. Some may end conclusively, while others will end gradually as design iterations become less and less useful and research questions become more and more thoroughly addressed. Lawson (2005) makes the point that design is never really finished; it is up to the expert designer to define a conclusion to his or her efforts. So it is with design science.

5.1. Theory

In the TDE model, the term “theory” is defined broadly (see Gregor, 2006), encompassing adoption of existing scientific theory as a design lens, consultation with domain experts, and review of project-specific design and content literature. This stage may also contribute to the generation of new theory, produced either from literature or from data, and conceptualized either prior to design of the IT artifact, during its development, or after its evaluation. The theory stage may be seen as both a beginning and an end to design science research: theory adopted early will inform design, just as new theory may eventually come out of it.

Gregor (2006) suggests five types of theory in IS: analysis (which says "what is"), explanation (which says "what is," "how," "why," "when," and "where"), prediction (which says "what is" and "what will be"), explanation and prediction (which says "what is," "how," "why," "when," "where," and "what will be"), and design and action (which says "how to do something"). Because of its nature as a design-oriented approach to inquiry, it might be argued that the theory stage of design science should concern itself primarily with Gregor's fifth "design and action" category. In fact, the theory stage could orient around any of the theory types she identifies. In addition to theorizing improved ways to "do something" (the interest of most designers), it is also possible to use design science to analyze a phenomenon within a design space or context, explain aspects of that phenomenon, and to predict future outcomes that may stem from design activities or their absence (interests more closely aligned with traditional social-psychological research). What is required is that the theory stage be used to frame the design science project's theoretical orientation, draw upon what existing theories may be relevant, and develop new theory if needed.

5.2. Design

The second core stage is design itself. Design science research revolves around the conceptualization, design, and development of an IT artifact, where theoretical and practical underpinnings shape a functional system, and the artifact (both during design and at various points of completeness or iteration) may help to produce new theory. The design stage can produce a rich data stream of systematically analyzed and characterized problems, theoretical knowledge applied in real-world contexts, highly contextualized use scenarios, deep understanding of users, expert knowledge about the design space gleaned from practitioners and domain experts, and a history of design decisions justified by careful consideration of all these elements. In addition, the artifact itself will represent a codification of much of this data - a culmination of often disordered activities that is itself orderly and concrete, with the potential to be dissected, examined, and studied at will. This is similar to Carroll and Campbell's (1989) notion that the IT artifact is an embodiment of theory. However, in the TDE model, theory is just one kind of knowledge that can be encapsulated in the IT artifact; various designer knowledge – some of which will be theory-driven, but much of which will not – will also be so contained.

The vision of design espoused in the TDE model of design science conforms to the expert view, a departure from other versions of design science that tend to adopt more conservative (and seemingly more scientific) approaches to design (Fallman, 2003). Nonetheless, designers and researchers both benefit from the design stage. Designers who grapple with the design space gain essential knowledge about its character and nature, improvements that can be made within it, and various constraints or opportunities that it imposes upon design. This knowledge is pragmatic and applied. As designers take the IT artifact through a series of iterations, the knowledge they gain will inevitably improve the artifact as a way of addressing the design space. Simultaneously, however, data produced during design processes can be of essential value to scholars who hope to understand broader social-psychological questions (i.e. not just, “does the artifact work?” and not just questions about designers or design activity). For example, the designer might ask, "what can I do to make this design more engaging for users?" and data produced over the course of design will help address this prescriptive question. The scholar might instead inquire, "What kinds of designed features are more or less motivating for users?" A well documented design process is an important step toward addressing this descriptive social-psychological science question.

5.3. Evaluation

The evaluation stage of design science research can be both a culminating event, when the IT artifact is finally placed into its use context and tested, as well as a beginning, when empirical findings motivate a fresh cycle of design, development, implementation, and evaluation. For designers, evaluation metrics can show how certain design decisions work (or fail to work) in practice, and can lead to new understanding of the artifact and its use. For scholars, the evaluation stage must be about more than simply saying "yes this worked," or, "no, this didn't work." Rather, it must be about the project's broader research questions. Adopted theory must be questioned in light of the evidence provided by the IT artifact as it is evaluated. New theory may be generated. A new understanding of social-psychological phenomenon should be gained.

Evaluation may be approached through any number of well-understood research methodologies, including focus groups, surveys, observations, talk aloud sessions, experiments, and even instrumentation of the artifact itself. In poorly understood design spaces, inductive or exploratory approaches may be critical for recognizing design requirements and developing interesting research questions. In better understood contexts, or where a design science project has matured past the exploratory stage, deductive approaches may also bear fruit, as specific design variables are manipulated and tested under controlled conditions. This implies the possibility of transitioning over the course of a design science project from more inductive, qualitative methodologies to more deductive, quantitative ones. Ultimately, however, the TDE model is methodologically agnostic; it is an approach to knowledge generation that values the design process and the IT artifact, but pragmatically acknowledges the highly variable conditions that impact design and scholarly activity in different domains and adopts varying evaluation methodologies accordingly.

5.4. Iteration

Theory, design, and evaluation each may be undertaken multiple times over the course of a project, not necessarily in that order, and not necessarily one-by-one. For example, a project may be predicated upon existing theory, a design instantiated, and an evaluation effort undertaken. Evaluation may lead to findings that are of both theoretic and practical value, motivating a return to theory (to reevaluate, modify, or even generate new) and a return to design (to improve the artifact). Each of these may motivate further iteration. Thus, the TDE model describes a complex series of connections between stages, occurring at different times and in different ways, depending on the needs of a given project. Lawson (2005) conceives of something similar when he dissects the various linear process models of design activity and notes how nonlinear design usually is in practice. He describes a revised view of design as, "a negotiation between problem and solution through the three activities of analysis, synthesis, and evaluation," (Lawson, 2005). The TDE model is similar, viewing design science as a negotiation between inputs (research questions plus a vision for the design space) and outputs (new knowledge plus the functional IT artifact). This negotiation takes place through the three activities of theorization, design, and evaluation.

6. Theory, Design, and Evaluation: Linear Variations

Though the TDE model is conceptualized as a non-linear and complex interplay between theory, design, and evaluation, it is useful to analyze several linear variations of the theory, design, and evaluation core to demonstrate how the character of a design science research effort is impacted by varying start and end points. In this analysis, linear variations are grouped into three approaches: the scholar's approach (starting with theory), the designer's approach (starting with design), and the critic's approach (starting with evaluation).

6.1. The Scholar's Approach: Starting With Theory

The scholar's approach is so named because both of its two variations (theory > design > evaluation; theory > evaluation > design) begin with theory, a typical starting point for deductive scientific inquiry. In the scholar's approach, the TDE model begins with an attempt to discover and apply relevant theory to later design and evaluation processes. This theoretical knowledge – defined broadly (see Gregor, 2006) – may include actual scientific theories or models, rules of thumb and design guidelines (especially prevalent in applied sciences and design-oriented disciplines such as HCI or information visualization) as well as background information about context and users supplied by domain experts or through direct observation. Theory may be drawn from existing scholarly literature, but theories or models may also be generated as part of the current, ongoing research effort with an eye toward validation later in the design science process.

Following the theory stage, the scholar's approach splits into two possible paths. In the first, theoretical knowledge about the context of use, users, technology, and possible features of the artifact to be produced informs the design of an IT artifact. Following this, the artifact itself and the adopted theories are evaluated using well-understood research methodologies. The artifact itself will be evaluated on its functionality or fit to the context (i.e. What Dix (2010) calls "usability evaluation"), whereas the theory that motivated and framed its development may be evaluated more broadly in "evaluation for research," (Dix, 2010). Usability evaluation can answer the question, "did this IT artifact work as intended?" Evaluations for research, on the other hand, are important for producing natural/social-psychological science findings framed by the research questions established before or during the theory and design stages: e.g. "What features of this artifact are more or less motivating to users and why?" "How does the psychological model we developed apply to the design context?" "What is the impact of technology tools like the one we designed on the classroom experience?"

Usability evaluations and evaluations for research both can compel the designer-researcher to revisit earlier work in a fashion similar to the task-artifact cycle (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992). Practical and theoretical findings can impact future design iterations of the IT artifact or motivate the exploration of additional theory.

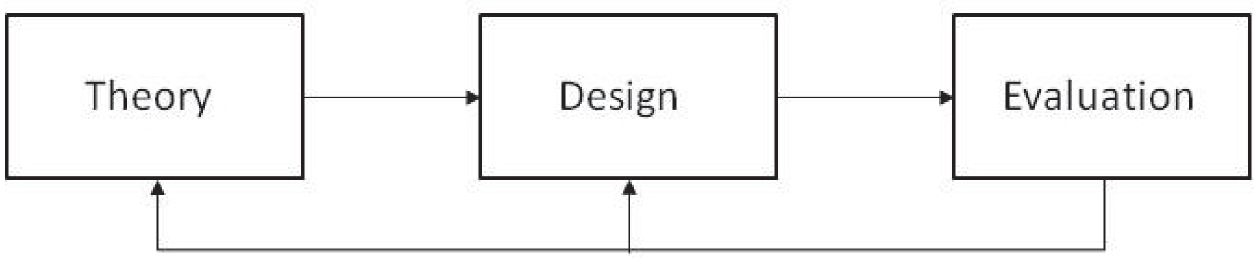

Figure 4.2. The Scholar's Approach (Path 1): Theory informs design, leading to evaluation of both.

In the second path of the scholar's approach, the theory stage leads to evaluation first, followed by design. This path is similar to traditional deductive science, in that theory (a hypothesis or set of hypotheses; an assertion about the world) is tested through observation and analysis (evaluation). There is no usability evaluation in this path, since no IT artifact has yet been created. Rather, evaluation is entirely for research, validating or testing the central concepts of the theory stage. Stopping at this point would produce a conventional research study such as can be found in many disciplines, including HCI.

However, the traditional scholarly path can easily become a design science effort by including a design stage in the process. Drawing upon theorization and subsequent evaluation, designers and scholars may conceptualize, design, and develop an IT artifact with the intention of exploring earlier findings and implications in an applied setting. As in the first path, the second can be highly iterative, with the possibility of returning from the final design stage back to either theory or evaluation: a return to evaluation may improve the IT artifact (usability testing) or further test theories that were able to withstand prior evaluation; theories themselves may be refined, reformulated, or even rejected based on this evaluation or the design process itself.

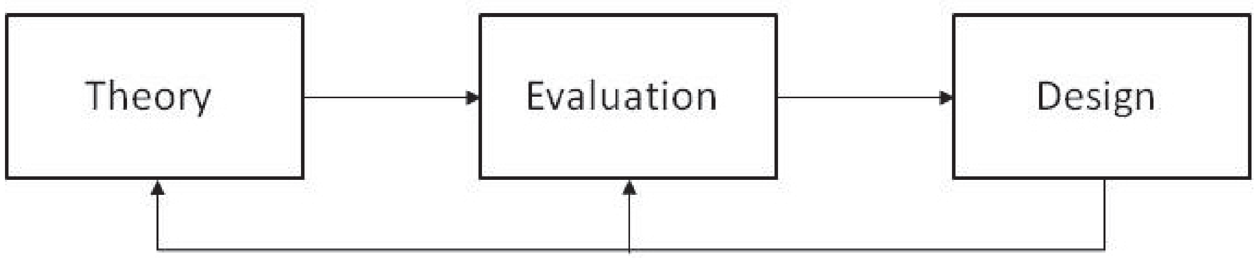

Figure 4.3. The Scholar's Approach (Path 2): Theory and evaluation motivate applied design activities.

Path two of the scholar's approach is similar to the usual expected path for scholarly work in applied disciplines, where basic research findings that may be of value to practitioners are applied in various design efforts to see how valuable they truly are. In HCI, this work is often left to practitioners; however the TDE model integrates these efforts into the research process, ensuring that basic research findings are applied as originally conceptualized to practical design efforts.

6.2. The Designer's Approach: Starting With Design

The designer's approach also has two paths (design > evaluation > theory; design > theory > evaluation), both of which begin with a design stage. The designer's approach is so named because both of these paths closely reflect the expert designer point of view posited by Lawson (2004, 2005; Lawson & Dorst, 2009) and others (e.g. Boling, 2010; Christiaans & Venselaar, 2005; Cross, 1999, 2004, 1984; Cross et al., 1981; Gero, 1990; Smith, 2010; Stolterman, 2008).

In the designer's approach, the TDE model begins with design activity in the expert tradition; a designer with a vision of how the existing state of the world can be improved in some way addresses this through design. As in the scholar's approach, the designer's approach can split into two paths. The first path transitions from design to evaluation; the designed IT artifact is evaluated for how successfully it has addressed the problem space. Because little formal theorization has yet occurred, this is largely limited to usability evaluation (Dix, 2010). To this point, path one is essentially a mirror of design practice. However, just as the second path of the scholar's approach appended design activity to traditional science, so the first path of the designer's approach appends theory to design practice. In this path, design and evaluation can lead to insights that are theoretical and generalizable. For example, the design and usability evaluation of a visualization tool for classroom use may spark insights into the broader nature of technology use in the classroom. Because the TDE model is iterative, the theory stage may direct the designer-researcher back to prior stages; a more theoretically-based evaluation or a second round of design based on theory (or both) may be desirable.

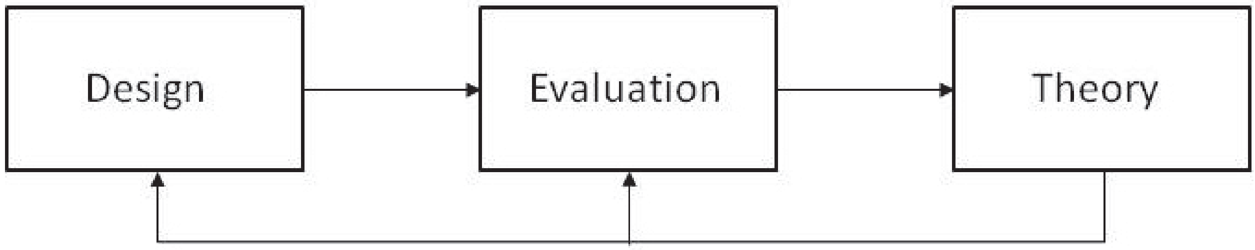

Figure 4.4. The Designer's Approach (Path 1): Design practice and subsequent evaluation help to generate new theory.

Path two of the designer's approach progresses from design to theorization to evaluation. This path is similar to path one, the key difference being that theory in the first path may come from both design activities and evaluation data, while in path two, theory is the result of reflective design practice only. This path makes sense when the IT artifact is considered an encapsulation of theory itself, as Carroll and Campbell (1997; Carroll & Campbell, 1989) describe. It also makes sense when appraised from the pragmatic design perspective, where deep reflection on design activities can produce meaningful insights.

Evaluation in path two is directed at the IT artifact itself, as well as any theory that the artifact represents or helped to generate. This is to say that path one of the designer's approach is much more like design practice than path two, which is like practice at the start, but soon shifts to scholarly approaches and perspectives.

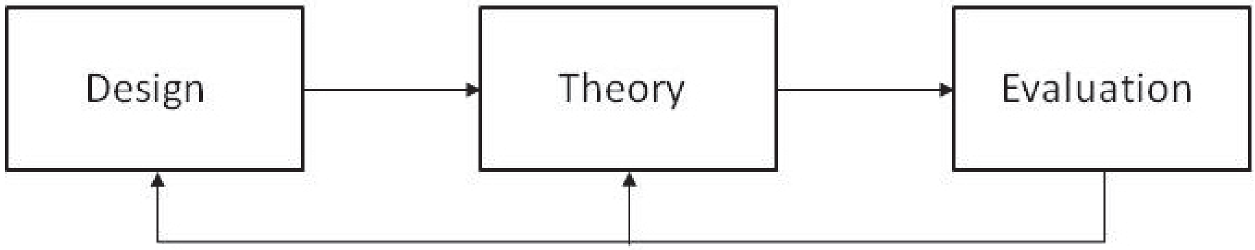

Figure 4.5. The Designer's Approach (Path 2): Design practice suggests theory, and then both are evaluated.

Both paths of the designer's approach share commonalities with Fallman (2003) and Lawson's (2004) view of sketching and prototyping as a process of inquiry. In each path, design activities themselves serve as a form of knowledge generation, though both lead eventually to more formal and scientific methods of asserting this knowledge and testing it.

6.3. The Critic's Approach: Starting With Evaluation

The critic's approach is so named because it begins with critique in the form of evaluation – systematic observation and analysis. It may seem odd to suggest that design science can begin with evaluation, when no other work has yet been undertaken. However, because the TDE model adopts the expert view of design, it also subscribes to the notion that prior precedent and examples can (and, indeed, must) influence design. This is related to the pragmatic view of design, where design occurs in, "a world which is already crammed with people, artifacts, and practices, each with their own histories, identities, goals, and plans," (Fallman, 2003). In the critic's approach, design science can begin with a critique of IT artifacts that already exist, either as the result of previous design science efforts or because they are already part of the world at large. In addition, evaluation may center on other things: the nature of a phenomenon that has been observed, the interests or goals of potential users, or the requirements of any potential IT artifact to be designed (Browne, 2006). Evaluation may also begin with an exploration of existing theory from a more scholarly perspective.

The critic's approach eventually branches into two separate paths. Path one uses initial evaluation to inform a new theoretical stage, where existing theory is scrutinized or reevaluated and new theory may be generated. Up to this point, path one mirrors inductive scientific processes, where observational science leads to theorization and explanation. However, in the TDE model, a design stage follows, in which inductively produced insights are used to inform the design of an IT artifact.

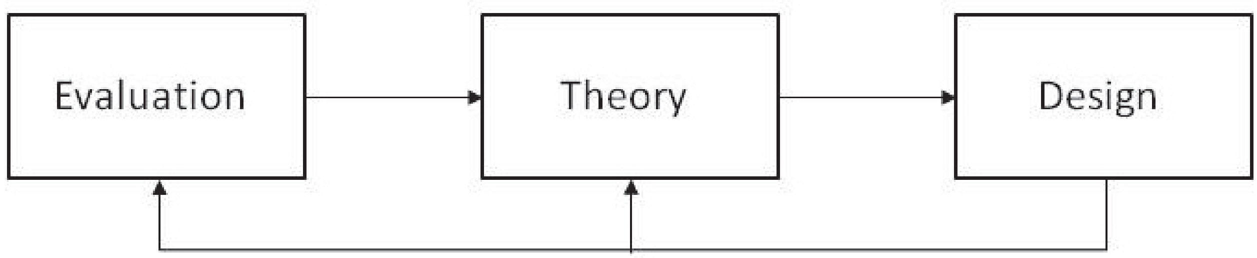

Figure 4.6. The Critic's Approach (Path 1): Evaluation of existing artifacts or theories leads to new theorization and design.

In path two of the critic's approach, evaluation of existing IT artifacts or theories can inspire design directly, leading to the development of a new IT artifact. This artifact can then become a vehicle for theory generation. Path two is a form of inductive science where design becomes an important element of knowledge generation, rather than an outcome per se. This path is akin to Järvinen's (Hevner, 2007; Järvinen, 2007) view that design science is a form of action research; evaluation of a set of circumstances (the context) can lead to a design intervention and the development of new knowledge about the design and its interaction with the context (theory).

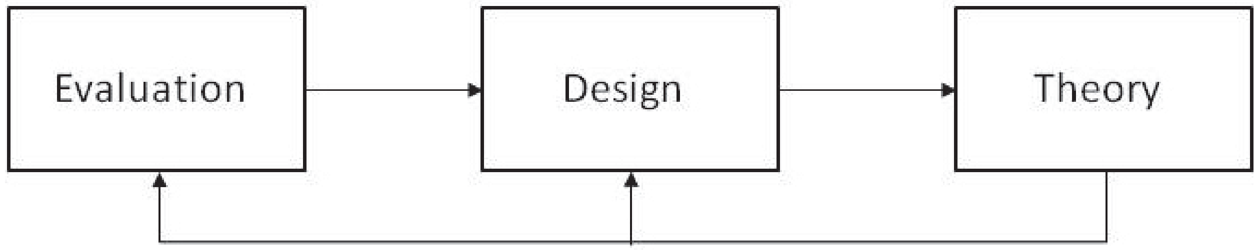

Figure 4.7. The Critic's Approach (Path 2): Evaluating of artifacts and theories leads to design intervention and theorization.

Like the other approaches, the critic's approach is iterative. Late stages of the process can (and often should) direct the designer-researcher back to early stages. The culminating IT artifact produced in path one may inspire new rounds of evaluation or theory; the theoretical knowledge produced in path two will motivate new design efforts or new evaluation (both usability evaluation and evaluation for research).

6.4. Summary of the Linear Variations

The following table summarizes the six linear variations of the TDE model:

	Summary of TDE Linear Variations		
	Order	**Analog To**	**Dominant Perspective**
Scholar, Path 1	Theory > Design > Evaluation	IS Design Science	Both
Scholar, Path 2	Theory > Evaluation > Design	Deductive Science	Scholar
Designer, Path 1	Design > Evaluation > Theory	Design Practice; Sketching-as-Inquiry	Designer
Designer, Path 2	Design > Theory > Evaluation	Artifacts-as-Theories; Sketching-as-Inquiry	Both
Critic, Path 1	Evaluation > Theory > Design	Inductive Science	Scholar
Critic, Path 2	Evaluation > Design > Theory	Action Research	Scholar

Table 4.1. Summarizing the TDE linear variations, showing how they are ordered, their analog(s) from literature, and which perspective (designer, scholar, or both) dominates.

The six linear variations of the theory > design > evaluation process are a helpful analytical tool, but the TDE model as a whole acknowledges that design science in the real world rarely occurs in such a linear, organized fashion. The instability and complexity of design science research lays bare the illusion that research is always conducted procedurally and divorced from context, flexibility, intuition, and ill-definition. The TDE approach or any other can be iterative, nonlinear, and sometimes even chaotic.

For example, a design science project following the TDE model might begin with the first path of the critic's approach (evaluation > theory > design). At the point when design occurs in this path, the linear variations imply that the design science project should be over, or that a reflection back to early stages might occur. Rather, scholars may in fact have stumbled into the middle (design stage) of the scholar's approach (theory > design > evaluation). Linear variations of the TDE model can easily intertwine with one another as different aspects of the design and research process are reached. In a sense, a design science project can continue ad infinitum; it must conclude based on the judgment of the researchers and designers involved, rather than any standardized "end point" dictated by the model alone.

The three stages of the TDE model, no matter in what order they are undertaken, are also not as separate as the linear variations imply. Theorization can occur simultaneously with design or evaluation; evaluation may be ongoing during design. The three stages are named more for the activities they encapsulate than because they represent discrete and orderly phases of research. So, despite the usefulness of analyzing theory, design, and evaluation as a series of linear, discrete components, in the TDE model these elements are represented in a more ambiguous, overlapping, and cyclical diagram as follows:

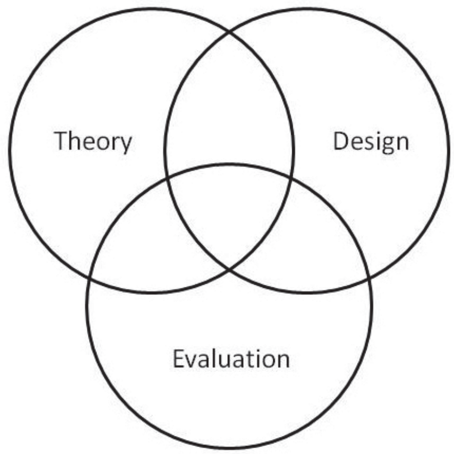

Figure 4.8. Representing the interplay of theory, design, and evaluation in the TDE model.

7. Outcomes: IT Artifacts & New Knowledge

All models of design science describe new knowledge and IT artifacts as important outcomes. In the TDE model, this is also the case. Because the TDE model envisions scholarly activity happening in parallel with design activity, however, these two outcomes take on a slightly different character from other models.

7.1. Design Outcomes

The primary design outcome from the TDE model is a functional IT artifact. Hevner et al. (2004) describes IT artifact as, “constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems).” In the TDE model, the notion of artifact is slightly weighted toward the idea of instantiations – functional IT systems that can be used and evaluated within the context for which they were intended. Over the course of developing an instantiation, however, designers and scholars working closely together will often develop constructs, models, and methods complementary to the instantiation that is the focus of design.

Lawson (2004, 2005; Lawson & Dorst, 2009) paints the notion of design with a broad brush; many of his examples are architectural, however he also includes engineers, graphic designers, fashion designers, user experience designers, and many others in his perspective of design and designers. The TDE model also adopts this broad view, and instantiations developed with it could take many forms: architectural structures, visualizations, information graphics, clothing, communication tools, games, computer interfaces, information systems, web sites, software, computer hardware, new products, etc. Here, discussions of the TDE model are directed toward the HCI community. Some of these examples seem like a poor fit for HCI. However, augmented reality systems and smart devices are of keen interest to HCI scholars (Azuma, 1997; Azuma et al., 2001; Helal et al., 2005; Norman, 2007), as are wearable computers (Amft & Lukowicz, 2009), so it is certainly not difficult to envision how designers from non-HCI disciplines like architecture or fashion design could become involved in HCI design science activities. Such a broad range of design perspectives, coupled with an equally broad range of scholar insights, can produce a virtually endless stream of new, interesting, and useful IT artifacts.

7.1. Knowledge Outcomes

Both scholars and designers generate new knowledge as they undertake scientific and design activities. Scholarly knowledge is produced through traditional application of the scientific method. Natural science or social-psychological science research questions are proposed, and these are directed toward areas where the design and development of an IT artifact will be helpful in answering them. For example, scholars interested in visualization tools for the classroom might ask questions about the impact of those tools on the instructor or student experience: their engagement with the learning material, frustrations they encounter when adapting technologies to the learning environment, sources of distraction, motivation to seek out new information individually, and learning outcomes from the technology itself. Scholars could also ask about ways to approach the design of learning tools (design methods) or develop models for technology use in learning environments. Technological questions might also be of interest: new functionalities, techniques, technologies, algorithms, etc. that may be useful (or perhaps harmful) when they are applied to classroom learning technologies. A TDE design science initiative in a different context would have different research questions and produce a different IT artifact. The possibilities are limited only by the imagination and interests of the designers and scholars involved.

Over the course of design and research, questions are normally refined and may eventually be turned into testable hypotheses. This scholarly activity can take place along both deductive and inductive lines, as well as through action research or even sketching or prototyping activities. The design process itself can be one way to explore research questions, and evaluation of the IT artifact – in controlled settings like experiments, as well as over the course of real world use – can be another. These data, collected across the entirety of the work, can be analyzed and reported just as in more traditional non-design projects.

7.3. Dissemination of Outcomes

Hevner et al. (2007; Hevner et al., 2004) suggest that dissemination of design science outcomes is critical to the overall success of any such effort. In the TDE model, the notion of two parallel paths in a design science undertaking – scientific discovery and design action – was developed precisely because of Peffers et al's. (2007) warning about how design science results might be misinterpreted. In the TDE model, the two separate perspectives mean that results can be carefully constructed for different audiences with different interests. Scholarly outcomes can be reported in a traditional manner to the communities where they will have the most impact, while design outcomes can be disseminated in a host of less formal ways: released to domain experts and users directly, published as case studies in design-oriented venues, demonstrated for other designer-researchers at conferences, made available online for download, described in white papers, written up in journalistic venues, posted about in blogs or social media outlets, presented in video tutorials, and even propelled into the marketplace as commercialized products.

The parallel activities which take place in TDE design science research mean that a given project will have far more than just one scholarly contribution and one design contribution. Design and research are both complex, multi-faceted processes, so it is expected – and, indeed, desirable – that their interplay will spin off many different scholarly papers reporting on different aspects of the work, as well as many instantiations (progressive versions, or even entirely different designs to explore different approaches to the problem space), constructs, models, or methods (Hevner et al., 2004). All of these outcomes, as they filter through various dissemination mechanisms, become an embedded part of the scholarly and design knowledge base – precedent for new design and scholarly activity to come.

8. Tension

Zimmerman, Forlizzi, and their colleagues (Forlizzi et al., 2008; Forlizzi, Zimmerman, & Stolterman, 2009; Zimmerman & Forlizzi, 2008; Zimmerman et al., 2007; Zimmerman, Stolterman, & Forlizzi, 2010) illustrate the different designer and scholar perspectives that influence a design science project and frame these as mainly beneficial. In the TDE model, inherent differences in viewpoint between designers and scholars are similarly viewed as an opportunity to produce unique interdisciplinary contributions. Nonetheless, the TDE model acknowledges that the different goals held by designers and scholars will normally create tensions that must be addressed – tradeoffs, compromises, complications, biases, and challenges that result from the competition between scholarly and design goals.

8.1. Differences in Perspective

The TDE model envisions designers and scholars working together to address a common problem space, though in different ways. Designers seek to solve the problem through the design of an IT artifact, while scholars seek to understand its nature – as well as the nature of other phenomenon related to it – via a course of scientific inquiry. These two approaches are complementary, as when research questions have a direct bearing on design decisions, or when particular design approaches enable certain kinds of research questions to be answered. However, designers and scholars in the TDE model necessarily view the problem space differently from each other.

For designers, the three core stages of theory, design, and evaluation will be most relevant when they are directed at design practice: developing an IT artifact. Theory, for the designer, can be defined very broadly indeed, as a host of background information from an array of sources becomes a foundation for design. This may include the designer's own expert knowledge of design, domain expert knowledge on the context and problem, user input, prior precedent and design examples, and even creative inspiration or innovation, sparked by virtually anything in the designer's own experience. For the designer, all of these elements help to theorize and define the beginnings of an IT artifact. Many of them may also be viewed as successful design outcomes as well, as the designer's own worldview and experience (and by extension, the knowledge he or she can make available to other designers) will necessarily grow and change over the course of design.

Design activities themselves are also viewed differently by designers than by scholars. To a designer, the design stage is primarily an activity to address the problem space and solve a difficult design challenge. The resulting IT artifact is judged by the designer primarily on its merits as a solution to this challenge: "did it work?" The IT artifact is a success if the problem is mitigated or solved; it is a failure if the problem remains or worsens. In the design stage, domain experts are viewed as partners or clients, and the IT artifact's users are perceived as customers.

Finally, designers perceive three primary roles for evaluation. First, evaluation can be used to make the IT artifact better, using what Dix (2010) would call a "usability evaluation." Second, this kind of evaluation can also spark new iterations of design when fundamental flaws or important opportunities are identified. Finally, the culminating evaluation of the IT artifact can be a test of whether the design works as intended and solves the problem it is supposed to address.

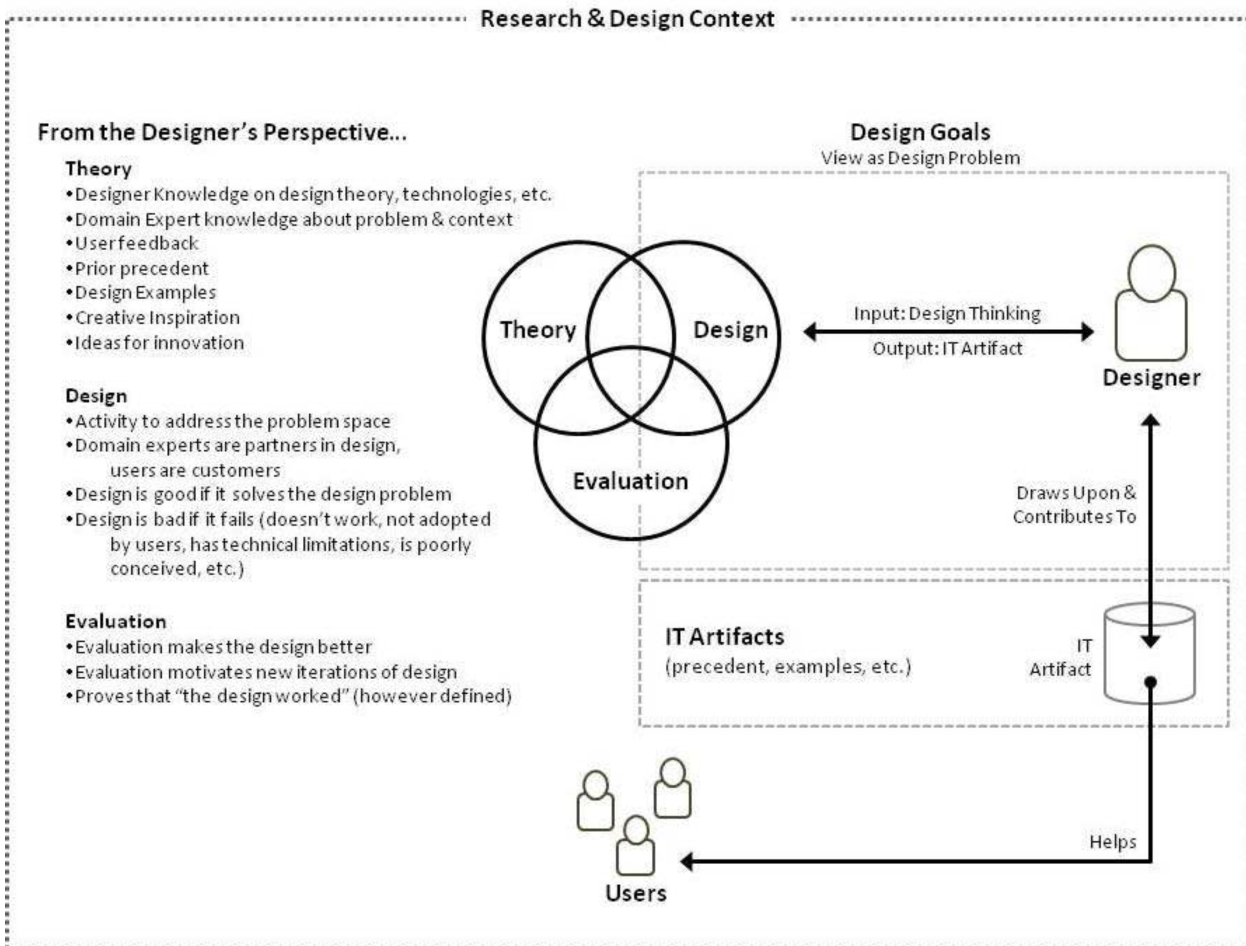

Figure 4.9. The TDE model from the designer's perspective; a view that is practice-based.

For scholars, the view of the TDE model is somewhat different. Scholars view the theory stage more narrowly, seeing it as an opportunity to draw upon existing scholarly theories from literature or to generate new theory from their own observations and analysis. As Gregor (2006) notes, there is room in these activities for information culled from domain experts, users, prior precedent, etc. However, most scholars will expect this knowledge to be formulated into a rigorously defined and developed theoretical model, rather than simply applied directly to design.

Scholars may also view the design process through their own scientific lens. To a scholar, design is an activity for addressing research questions by building IT artifacts that will become useful tools: tools to collect data, tools to test assertions about use, tools to explore theory, etc. Accordingly, design activity itself may be viewed as less important to overall scholarly goals than its finished product, and design decisions should only be made when they are rigorously justified with scientific knowledge. In the scholar's view, domain experts are partners in the research, but both they and users may also be viewed as participants and a source of data. The finished IT artifact will be judged as a generator of new knowledge; an IT artifact that fails to solve its intended problem may still be judged a great success by the scholar if it produces a good understanding of why this is so.

Scholars view the evaluation stage differently than designers as well. Evaluation of the IT artifact will address natural or social-psychological research questions, not just whether the IT artifact works or not. Evaluation may also incite new research questions and explore the problem space, design processes, the context, users, and use scenarios. Finally, evaluation will be valuable for testing the various theories that informed the design or were developed as an extension of it.

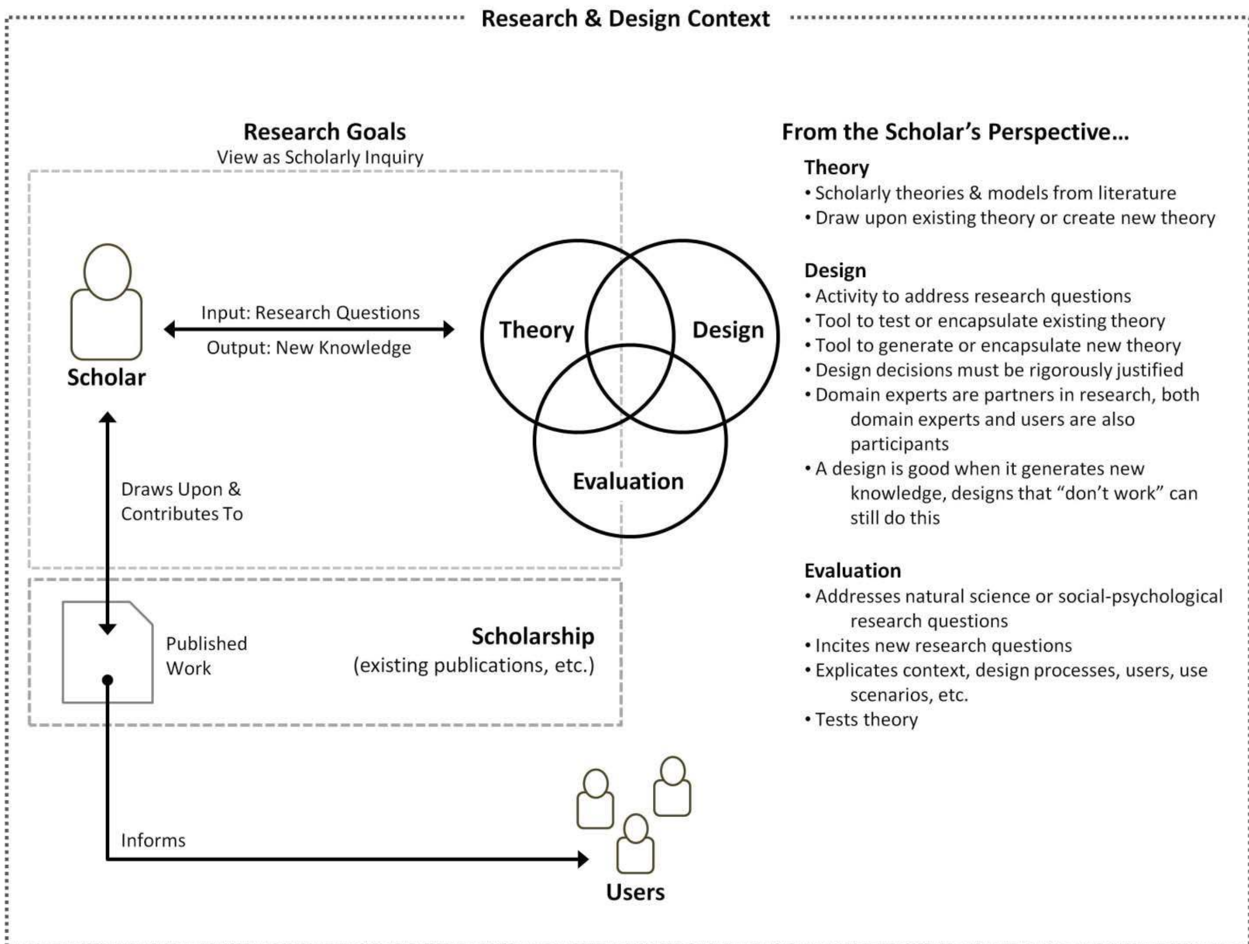

Figure 4.10. The TDE model from the scholar's perspective; a view that is science-oriented.

The parallel nature of design and scholarly activities in the TDE model creates tension, as designers pull activities more toward design practice, and scholars pull activities more toward scientific inquiry. An important side-effect of this tension is that the three core stages – theory, design, and evaluation – may actually be addressed at different times and in different orders by scholars and designers who are working together on the same project. For example, a designer may address the problem space by beginning with his or her view of theory, followed by design, and then a round of usability evaluation. For the scholar, the designer's theory stage may be of only limited use for answering research questions. He or she may only become deeply involved in the project during design, and may insist upon more scholarly forms of evaluation leading to a culminating theory before the project is finished. So while the designer approaches the project in the order theory > design > evaluation, the scholar may order it as design > evaluation > theory.

Early in such a project, scholars may feel that activities are not scholarly enough to bother with; designers may feel as though their scholar partners are uninterested in some of the most important aspects of the work. Later, there is a risk that the designed IT artifact will not be suitable for scholarly evaluation of research questions, or that the scholarly theory produced could have been developed and applied to the design earlier. Mitigating this kind of tension can be very difficult, and requires a strong partnership where both parties work closely together to understand the overall objectives of the project and do not insist upon thwarting the core stages to emphasize only their own design practice or scholarly purposes. Galison's (1997) notion of "trading zones," which suggests using a negotiating process to ensure that the requirements for various stakeholders in a collaboration are met, may be helpful when working with partners from different disciplinary backgrounds. A project lead or another researcher may take on the task of coordinating various groups and ensuring that individuals holding the design perspective and individuals holding the research perspective are both accommodated.

In some cases, especially smaller research projects, the design science researcher will also serve as a project's lead (or only) designer. These designer-researchers must be careful to take on design tasks only when they are qualified to complete them; scholarly and design outcomes can be of questionable value if design activities suffer at the hands of an amateur.

Of course, the same can be said of designers who take on scientific activities for which they are unprepared.

The phrase, “we’ll get some students to do the design,” is commonly heard on many design-oriented projects, most often because student developers are available, eager to gain experience, and inexpensive to hire. Because the TDE model adopts the expert view of design, this is a significant concern. Student designers, by definition, are not expert designers. Lawson (1979, 2004, 2005; Lawson & Dorst, 2009) and others (Akin, 1986; Darke, 1979; Eastman, 1970; Hillier et al., 1972; Rowe, 1987) have shown how student designers and expert designers act very differently when addressing a design problem, with experts performing more efficiently and usually producing better and more innovative outcomes than students. This is not to argue that student developers should not be invited to participate in design science project; to the contrary, students can make valuable contributions and benefit tremendously as learners. It is important, however, to have design activities overseen by someone who is an expert, be it the designer-researcher him or herself, the design member of a partnership, or even a hired professional. Including a design expert on design science projects will make it much easier to successfully (as defined by both designer and scholar) address challenging design problems.

In cases where the roles of designer and scholar are contained within a single individual, bias can be a particularly difficult problem to address. Data collected during evaluation – especially usability evaluation – can (and often does) include criticisms and complaints. A single designer-researcher must be careful to accept and appreciate such data for its value, rather than seeking to defend or justify design choices in the face of criticism. This is easiest to do when the scholar's perspective is intentionally donned, and the designer-researcher can keep firmly in mind that critiques can only serve to make the designed system better and that negative feedback is often more valuable to system improvement and scholarly outcomes than compliments and praise. Accepting such feedback can be difficult, as virtually all designers become attached to their work. More experienced designers often have an easier time casting aside ideas and avoiding bias; their experience dealing with various design constraints imposed by users and clients (Lawson, 2005) partially inure them to criticisms, feedback, and new ideas.

Even so, the risks for bias are high when the same individual develops and evaluates the IT artifact. This is why the TDE model may sometimes be more successful when a formal partnership between a separate researcher and designer is embedded into a given project. This allows an unbiased individual who is familiar with evaluation methodologies to undertake most kinds of formal evaluation in lieu of the designer, assuring that results are as unbiased as possible.

8.2. Feasibility

Overall project feasibility can be a source of tension as well. If a design problem is too difficult, it may tax the most ambitious designer; research questions may be similarly difficult to address with relatively simple design instantiations. There is a difference between commercial design and design science. In a commercial setting, the only goal is to solve problems for the client, and often, these problems have been solved many times before in many different ways; expert designers are well-suited for exploring this prior precedent and creatively applying it to slightly different contexts. In the design science setting, however, problems are often highly challenging and may differ greatly from prior relevant examples. In addition, the demands of research add an additional element of inquiry and discovery to virtually all design tasks. This can mean that even experienced designers can overestimate the feasibility of a given design science project.

9. Conclusion

This chapter proposed a new model for design science, called the theory, design, and evaluation (TDE) model. This model differs from previous models of design science because it embeds design and scholarship as parallel activities within a single process of inquiry, rather than attempting to justify design as a scientific undertaking per se. In addition, this model adopts an expert view of design, where knowledgeable designers draw upon their design experience, knowledge of prior precedent, and repertoire of techniques to address challenging problems. This view of design contrasts with the more engineering-oriented, structured, conservative view of design that is adopted by other process models of design science, especially those found in the IS field.

In the next chapters, papers from three different TDE design science projects are presented. These projects demonstrate how the TDE model can be used for design science research in a wide range of contexts to address an array of design problems and research questions. The individual papers by themselves show just one small segment of the activity undertaken on each project in its entirety. In a culminating discussion, the three projects will be discussed in greater detail, and a variety of future directions for each will be explored.

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CHAPTER 5: Demonstrating the Theory, Design and Evaluation (TDE) Model

1. Method Justification

It is important to demonstrate that the TDE model of design science can work as suggested. One way of doing this is to show how it has been used in real-world design science projects, and how those projects are producing the kinds of design activities, scholarly initiatives, and knowledge/design outcomes that the model prescribes. This is a typical approach to validation in the design science literature, adopted by a variety of scholars writing on the topic (e.g. Fallman, 2003; Hevner, 2007; Hevner, March, Park, & Ram, 2004; Nunamaker, Chen, & Purdin, 1990; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007; Zimmerman, Forlizzi, & Evenson, 2007). Most models of design science are presented with one or more examples of the model in action on existing design science projects. This present thesis complies with the established standard.

2. Method

Three ongoing design science projects are used as demonstrations of the TDE model in action. Full papers, one for each project, are included as the next three chapters of this study. Each paper is a demonstration of the kind of knowledge outcome that can be produced by the TDE model:

1. *Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case*, by Nathan Prestopnik and Kevin Crowston
2. *Web Nuisances and Coping with Negative Emotions: Empirical Investigations and a Theoretical Model,* by Nathan Prestopnik and Ping Zhang

3. *Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO)*, by Nathan Prestopnik and Alan Foley

Together, the selected papers showcase knowledge outcomes from their respective TDE design science projects. These projects were chosen as examples because they explore different design and research contexts, feature different relationships between design and scholarly partners, enact the TDE core of theory, design, and evaluation differently, have produced different scholarly and design outcomes, and have consequently been impacted by different kinds of designer-researcher tensions. The three projects together demonstrate various successes of the TDE model, as well as its flexibility in the face of highly variable problem spaces.

Following presentation of the papers themselves, the final discussion and conclusion chapters broaden the perspective on these three projects. Additional details and connections to the TDE model of design science are examined, and future directions for each project are explored.

3. Paper Introductions

3.1. *Citizen Sort*: Purposeful Gaming & Socio-Computational Systems

Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case (Prestopnik & Crowston, 2012b), details theoretical, design, and preliminary evaluative components of an ongoing design science research project called *Citizen Sort*. This project was undertaken in the socio-computational systems/citizen science context. Citizen science is a crowdsourced approach to collecting and analyzing scientific data, where ordinary members of the public can participate in scientific collaborations (Cohn, 2008; Wiggins &

Crowston, 2011). In the *Citizen Sort* project, a series of games and tools were developed with the dual purpose of supporting citizen science activities (the taxonomic classification of plant, animal, and insect species) and exploring the nature of motivation, engagement, and data quality in purposeful citizen science games.

The included paper details the design activities undertaken by the design science partnership, a group consisting of designers, researchers, domain experts from the biological sciences, and a large team of student programmers and artists. The paper also address some theoretical aspects of the project, drawing, for example on motivational theories by Crowston and Fagnot (2008) as well as those of Malone, Laubacher, and Dellarocas (2009), and similarly addresses preliminary evaluation of the designed systems. This project has most closely followed path two of the TDE critic's approach (evaluation > design > theory), though the project's activities have been occurred much less linearly than this implies. In early stages of *Citizen Sort*, other citizen science initiatives were evaluated through analysis of their web-based systems and interviews with their key scientific and development staff. This led to a design stage, which gradually transitioned into theorization. The project is planned to revert to evaluation and further theorization before it is concluded.

Citizen Sort has produced a variety of knowledge and design outcomes to date. Published scholarly material from this project has included work on the technologies that compose citizen science systems (Prestopnik & Crowston, 2012a) as well as a design overview presented at the 7th IEEE Conference on eScience (Prestopnik & Crowston, 2011). Design outcomes include a project website and two classification systems: 1) the game *Happy*

Match which lets players win points for classifying photos and 2) *Forgotten Island*, which embeds the classification activity into an adventure game. A third system, an expert tool designed to develop taxonomic keys out of large collections of unclassified images called *Hunt & Gather*, is still under development.

3.2. CONE: Online Nuisances and Annoyance Coping

Web Nuisances and Coping with Negative Emotions: Empirical Investigations and a Theoretical Model, by Nathan Prestopnik and Ping Zhang, is an exploratory study of online nuisances (things like pop-up advertisements, loud sounds, animations, or other people's annoying behavior). This work differs from previous online nuisance research by focusing holistically on the online nuisance landscape, rather than on just one or two specific kinds of nuisances. Developed out of prior work (Prestopnik & Zhang, 2010), the paper draws upon two psychological theories, reactance theory (J. W. Brehm, 1966; S. S. Brehm & Brehm, 1981) and the theory of psychological stress coping (Lazarus, 1966, 1993; Lazarus & Folkman, 1984). It presents a new model: the Coping with Online Nuisance Encounters (CONE) model, which is developed out of an empirical study using focus group and online survey data. The paper heavily emphasizes theory and evaluation; design is discussed in terms of implications rather than concrete IT artifacts to be implemented. The paper is included as an example of path one of the TDE critic's approach (evaluation > theory > design), which is similar to traditional inductive scholarship.

Because of the scholarly approach for this project so far, the context is still relatively broad (online nuisances). However, the paper itself explores three more specific contexts: social media, organizational computing, and online advertising, of which online advertising is the most thoroughly studied. To date, the partnership consists only of scholars and study participants (i.e. sampled end-users). However, there are a variety of practical implications from this study that are likely to lead to design activity and a correspondingly more inclusive partnership.

Ultimately, *Online Nuisances and Annoyance Coping: Empirical Investigations and a Theoretical Model* is included for its emphasis on theory and evaluation rather than design. It is an example of how traditional scholarly research in HCI can be leveraged to design science purposes using the TDE model. In chapters nine and ten, the specific implications and future directions for this work are explored in more detail.

3.3. The Temporally Enabled Map for Presentation (TEMPO)

Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (Prestopnik & Foley, 2012), was developed out of a design science project (Prestopnik & Foley, 2011) in which a visualization system was conceptualized, designed, developed, and evaluated for use in the military history classroom. TEMPO addressed a key problem in military history education: the static nature of paper maps commonly used in this context. Paper maps do a good job of visualizing space, but do poorly when visualizing temporal information. The TEMPO project also addressed scholarly research questions about the impact of visualization tools on the student and instructor experience. In *Visualizing the Past: The Design of a Temporally Enabled Map for Presentation*, the TEMPO project is revisited and presented as a design case study. This paper provides more detail on the design activities surrounding TEMPO, but also illustrates how design activities can play a critical role in exploring a context and adopting or rejecting theory.

The TEMPO project formed a partnership between a designer and HCI/information visualization scholar, a scholar from the field of education, and domain experts from the field of history education. These partners approached the TEMPO project on path one of the scholar's approach (theory > design > evaluation), beginning with an exploration of relevant visualization and history literature, and progressing through a rapid design stage toward several iterations of evaluation using testing (see Hevner et al., 2004 for a discussion of different testing approaches), expert evaluation, and surveys.

The TEMPO artifact itself is an important design outcome of this design science project. Expert evaluators from the field of history education expressed a great deal of interest in the prototype TEMPO system, and there is a possibility that a more advanced and polished version of the tool could be successfully commercialized. This is one possible future direction for the project. In addition, the TEMPO project revealed how designing visualizations can produce a variety of benefits for those involved in the creative act. A second future direction for TEMPO may be to develop a visualization creation system that lets learners assemble and visualize data for themselves.

4. Example Paper Overview

The following table summarizes the three example papers, including their contexts, which of the three TDE stages (theory, design, and evaluation) they include, which linear variation they most closely match, outcomes so far, and possible future outcomes:

Included Papers & Project Overview							
Paper Summary					**Project Summary**		
Included Paper	**Context**	**T**	**D**	**E**	**TDE Linear Variation**	**Outcomes so Far**	**Future Outcomes**
Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case	Citizen Science; Purposeful Gaming; Life Sciences	Y	Y	Y	Evaluation>Design>Theory	Four papers (four published); one poster (published); one extended abstract (published); Four IT artifacts	Additional scholarly publications; possible design revisions to existing artifacts
Web Nuisances and Coping with Negative Emotions: Empirical Investigations and a Theoretical Model	Social Media; Organizational Computing; Online Advertising	Y	N	Y	Evaluation>Theory>Design	Two papers (one published)	IT artifact based on scholarly findings; scholarly work based on evaluation
Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO)	Military History Education; Classroom Lecture	Y	Y	N	Theory>Design>Evaluation	Two papers (two published); One IT artifact (TEMPO)	New IT artifact; possible commercialization; creative visualization tool

Table 5.1. Included papers and project overview.

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CHAPTER 6: Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case

Prestopnik, N.R. & Crowston, K. (2012). Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case. *ACM Group: International Conference on Supporting Group Work*. Sanibel Is., FL, 27–31 October, 2012. [1]

Abstract

Citizen science is a form of social computation where members of the public are recruited to contribute to scientific investigations. Citizen-science projects often use web-based systems to support collaborative scientific activities, making them a form of computer-supported cooperative work. However, finding ways to attract participants and confirm the veracity of the data they produce are key issues in making such systems successful. We describe a series of web-based tools and games currently under development to support taxonomic classification of organisms in photographs collected by citizen-science projects. In the design science tradition, the systems are purpose-built to test hypotheses about participant motivation and techniques for ensuring data quality. Findings from preliminary evaluation and the design process itself are discussed.

1. Introduction

Citizen science is a phenomenon where members of the public are recruited to contribute to scientific investigations (Cohn, 2008; Wiggins & Crowston, 2011). Notably successful citizen-science projects include asking participants to help classify astronomical photographs, report bird sightings, count insects in the field, or use spatial reasoning skills to align genomes or fold protein strings. Such activities draw many individuals into a cooperative endeavor toward a common scientific goal. They feature a mix of tasks that can only be performed by people (e.g., making an observation or classifying an image) supported by computational scaffolding to organize these efforts. As such, citizen science often relies on some form of socio-computational system. While citizen science has a long history, such systems are relatively new, providing a variety of open questions of great interest to those who study socio-computational systems, as well as to scientists who may wish to use citizen science approaches to support their own research.

An interesting and sometimes challenging issue for citizen science is that some scientific topics are highly “charismatic” but many others are not. For example, bird watching, astronomy, and conservation all have existing communities of interest and a certain appeal, even for non-enthusiasts. However, important work is also being conducted in areas that attract much less public interest, such as moth, mold, or lichen classification. While enthusiasts exist for virtually all areas of the natural sciences, socio-computational systems rely on attracting large numbers of participants. As a result, the motivations of citizen science participants are important to understand, to attract new participants and retain old ones.

Furthermore, while some citizen scientists are quite expert, many are not and indeed, many may be novices. Therefore, successful projects must develop scientific tasks that can be performed by novices, while still ensuring the interest of those with more experience. Assuring the quality of data produced by the non-expert citizens using these systems is also of concern. The specific interest of this research, therefore, is to explore the relationships that exist between citizen science, socio-computational system design, attraction and retention of participants, and the impact of these on data quality.

Unfortunately, it is difficult to use current, real-world citizen-science projects as vehicles for exploring motivation, participation, users, technology, and data quality. The challenges are practical: citizen science project developers, researchers, and managers have little time available to devote toward research projects not directly related to their specific object of inquiry. Because currently instantiated citizen-science projects are working production systems, it is difficult to adjust project parameters, conduct experiments, issue surveys, interview participants, or otherwise gather information about the citizen science phenomenon. Invasive data collection efforts are likely to be disruptive and may have deleterious impacts on existing participant enthusiasm and data quality. In short, the potential drawbacks of granting complete access to socio-computational researchers outweigh any benefits that might accrue.

On the other hand, low-impact methods of investigation (e.g., interviewing or surveying staff members or researchers, passively gathering information about project websites and systems, etc.) are less likely to produce data required to address motivational and data-quality questions. Studying citizen science without fine control over the systems of interest creates a different problem: artificiality will infect any knowledge generated by such research, as simulations, mock-ups, and de-contextualized inquiry substitute for realistic exploration of actual systems that are highly situated within complex problem spaces.

We address these challenges by developing socio-computational systems explicitly designed to serve a dual purpose: as vehicles for scientific inquiry and as functional and useful systems built and deployed to solve specific, real-world problems. Building systems is not a new approach to research, but the approach has recently been reconceptualized under the name design science. This approach resides in the familiar territory of system design and evaluation, but wraps these well-known activities around a broader research agenda targeted at natural or social-psychological science. The strength of this approach is that complex phenomenon such as socio-computational systems and/or citizen science can be explored in a very realistic manner, while maintaining a great deal of control over the user experience.

The remainder of this paper is divided into three parts. First, a discussion of design science is presented. Second, an ongoing design science project in the socio-computational and citizen science domains is described. This project involves the creation of several games and tools to support an important science task in the biological sciences: species classification. Finally, results from the design process so far and from preliminary evaluations are reported, including discussions of the design science approach as a vehicle for socio-computational systems scholarship.

2. Design Science

Design science is an approach to scholarly study that couples traditional research methodologies with the development of an IT artifact to address natural science or social-psychological research questions coupled with design-related problems (Hevner, March, Park, & Ram, 2004; March & Smith, 1995; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Design science is practiced (mostly without using the term) in many domains, particularly human-computer interaction (HCI) and computer science (CS) more generally. The term and its formal conceptualization come from the field of information systems (IS), where system design is often viewed as atheoretical and so not research. In this setting, rigorous conceptualizations of design as a research tool are necessary to encourage its broader acceptance. However, even in fields where system design is generally embraced, the reconceptualization can be valuable, as the focus on designing useful artifacts often results in inattention to larger research questions. For example, in (Dix, 2010) many HCI evaluation practices are criticized as “usability evaluations” instead of scientific “evaluations for research”, what (Ellis & Dix, 2006) calls the “I did this and it’s cool” form of study.

Design science research has two equally important outcomes: 1) a functional IT artifact that helps address a specific, challenging, and practical design problem within a given context, and 2) meaningful scholarly contributions to a field of inquiry. Compared to typical social-science research approaches, the design science approach requires additional components, including interactions with subject-matter experts (SMEs), a situational focus on the context in which a design will be deployed as well as system building and testing. Compared to typical systems research, the approach requires explicit use of theory to guide design decisions and—importantly—an ability to draw more general conclusions about these theories from the experience of building the system.

The problem spaces addressed by design science inquiry are typically complex, sometimes referred to as “wicked” problems because they defy easy or obvious answers (Brooks, 1987, 1996; Rittel & Webber, 1984). Problems suitable for a design science approach include both those that are unsolved and those which offer opportunities for newer or better solutions (Hevner et al., 2004). However, to be meaningful to researchers outside of the specific problem space, the IT artifact must also become a vehicle for broader natural science or social-psychological inquiry. Theory, design and evaluation are thus interrelated in design science research, coherent pieces of a whole (Prestopnik, 2010) and conducted iteratively (Hevner et al., 2004; March & Smith, 1995).

Theory: The word "theory" is used broadly here (Gregor, 2006), encompassing the adoption of existing theory as a lens through which to approach design, as well as consultation with experts and review of non-theoretical, project-specific design literature. This stage may also result in the generation of new theory, produced either from literature or from data, and conceptualized either prior to design of the IT artifact, during its development, or after its evaluation. The theory stage may be seen as both a beginning and an end to design science research: theory adopted early will inform design, and new theory will come from it.

Design: Design science research revolves around the design of an IT artifact, where theoretical and practical underpinnings shape a functional system. The designed artifact may ultimately produce new theory, so artifact design must take future evaluation into account. The design scientist must always keep in mind the research questions to be addressed through research evaluation of the artifact.

Evaluation: The evaluation stage is about more than saying "yes this worked," or, "no, this didn't work." It must address the project's broader research questions by validating adopted theory or leading to the generation of new theory. Evaluation is not always an end point for research; evaluation will often suggest ways to improve the artifact (as a system to address the problem space or as a research tool) in its next design iteration.

3. Citizen Science Design Case

In this section, we describe our socio-computational system project situated in the citizen science domain, with emphasis on our research goals, the problem space, and design parameters.

3.1. Research Goals

Our study addresses two research questions. First, a critical issue in socio-computational system design generally, and citizen science systems in particular, is attracting and retaining enough participants to make achievement of project goals possible. Systems with too little participation will be unlikely to generate meaningful quantities of scientific data.

To address this question, we draw on psychological theories about motivation (e.g. Crowston & Fagnot, 2008). In (T. W. Malone, Laubacher, & Dellarocas, 2009), three basic motivations for individuals who are engaged in collective on-line activities are suggested: money, love, and glory. For citizen-science projects, offering payment to participants is rarely an option (project resources are typically too low), and most participants do not expect compensation for their efforts. Instead, participants indicate that inherent interest in the subject of scientific inquiry, the relevance of data collection efforts to particular interests or hobbies, the perception that a project will be fun and engaging, an interest in collaborate with experts, altruistic reasons, and hope for broader recognition as reasons for becoming involved in citizen-science projects (Bradford & Israel, 2004; King & Lynch, 1998; Raddick et al., 2009; Raddick et al., 2010; Wiggins & Crowston, 2010). These reasons match well with the notions of “love” and “glory” as motivators (T. W. Malone et al., 2009). There has been less scholarly or practical attention paid to how citizen science systems might be designed to motivate participants who do not hold these predominantly intrinsic motivations. As a result, most citizen-science projects rely heavily on participants who have preexisting enthusiasm for the scientific topic of the project, be it astronomy, bird watching, or classifying insects.

In the broader collective computing domains, several models for attracting participation have been deployed. In systems such as von Ahn's reCAPTCHA (von Ahn, 2009), which facilitates optical character recognition (OCR) on scanned books, the system is devised as an obstacle between users and their goals; reCAPTCHAs are used to verify that login attempts to web systems are coming from a human user, and to log in, users must use the reCAPTCHA tool. Other systems, such as the ESP game (an image tagging system) (von Ahn, 2007), Phetch (which produces accessible descriptions of images) (von Ahn, Shiry, Mihir, Ruoran, & Manuel, 2006), or TagATune (where users tag music clips) (Law & von Ahn, 2009) are designed as games, capitalizing on "love" forms of motivation, and giving people enjoyable activities to undertake while also producing meaningful work almost as a by-product.

Games in particular seem to have great potential as a motivator for participation and as a tool for producing high quality scientific data. However, from a review of citizen science websites (Wiggins & Crowston, 2011), it seems that few existing projects use games to motivate participation. Notable exceptions include *Fold It*, which disguises the science of protein string folding as a highly engaging puzzle game, and *Phylo*, where players compare genetic sequences in a colorful and abstract puzzle game. Both capitalize on human spatial reasoning abilities to solve problems that are difficult to automate. The *Fold It* player pages (http://fold.it/portal/players) reveals that more than 300,000 players are contributing to this project; furthermore, *Fold It* recently made headlines for an important AIDS research breakthrough generated by players of the game. Some projects, like *Stardust@Home*, incorporate game-like elements such as leader boards, high scores, or other participation metrics, but do not frame their scientific activities as games per se. Scholarly study of socio-computational games and games for citizen science may produce insights into how different participant groups can be attracted to citizen-science projects and motivated to participate in them.

Our second research question is about techniques for ensuring data quality, a necessary precondition for further scientific use of the data, but difficult for several reasons. First, for many scientific problems there is "ground truth," i.e. correct answers. Participant opinions are not as inherently valid as they might be in systems designed to produce, for example, image tags for search engines. For data to be scientific, valid, and accepted, the right answers must be produced by participants and confirmed by experts. Second, in many areas of science, specialized knowledge is required to provide data, but few citizen science participants are experts. Furthermore, the effect of systems (especially game-like interactions) on data quality is largely unknown. Therefore, finding methods to turn scientific tasks into things that non-scientists can do well, as well as finding techniques to confirm the validity of participant-provided data, are important research goals. To address these questions, we draw on theories from the problem domain, which we describe next.

3.2. Problem Space

The problem space we address in this design research comes from the biological sciences, particularly entomology, botany, and oceanography. In this domain, experts, enthusiasts, and curious members of the general public routinely collect and upload photographs of different living things. A photograph of an insect, plant, or animal, tagged with the date and location where it was taken, can provide valuable scientific data, e.g., on how urban sprawl impacts local ecosystems or evidence of local, regional, or global climactic shifts. However, to be useful, it is necessary to know what the picture is of, expressed in scientific terms, i.e., the scientific name of the species depicted. Some participants have the necessary knowledge (e.g., avid birders can generally identify particular bird species), but many potential participants do not.

To aid in identification of the species of specimens, biologists have developed taxonomic keys, which identify species from their particular combinations of characteristics, known as character-state combinations (i.e., attributes and values). The specific characters and states vary by taxon, but are broadly similar in structure. For example, a moth character might be its "orbicular spot," with states including, "absent," "dark," "light," etc. Given sufficient characters and states, it is possible to identify a photographed specimen to a specific family, genus, species, or even sub-species.

A challenging aspect of this problem is that researchers working within the same biological or ecological disciplines do not necessarily agree upon taxonomic keys. In fact, many researchers develop their own key variations to support their own specific research endeavors. Keys are therefore typically written for expert users, and are often complex, highly variable, and difficult to translate into a form that will be suitable for use in a socio-computational system, where expert understanding of characters, states, and taxonomic identification cannot be assumed.

A second challenge is that even with an established key, some characters and states are beyond the ability of most members of the general public to identify without training (e.g., the previous "orbicular spot" example). Others require true expert knowledge to apply (for example, classifying species by their sex organs). In some cases, especially for sub-species, true identifications cannot be made without access to specialized equipment; for example, some species are distinguishable only through their genetic makeup. This means that an IT artifact designed to support the classification task will be unlikely to effectively support both extremely knowledgeable users and extremely novice users; experts will require advanced tools with great flexibility, while novices may require simplified systems that have expert knowledge pre-built into them. In both cases, a web-based classification system will only be able to support some kinds of characters and states, while others will be impossible.

3.3. Design Parameters

To explore the motivations of citizen science participants and address the challenge of species classification in the biological sciences, a series of IT artifacts were designed and implemented. IT artifacts were designed and developed by a team of 21 professionals and students with varied technical and artistic expertise. Thirteen of the developers were hired on the project as either part- or full-time employees or volunteers. The remaining developers participated through their coursework (i.e. developing systems or components of systems for a class). Because this research is supported by a large and diverse group of developers, an ambitious program of design and development was organized, including five components that address specific aspects of the problem space, enabling exploration of our research questions.

3.3.1. Artifact 1: Citizen Sort

The IT artifacts hosted on the *Citizen Sort* website include both tools and games, organized along a continuum from “tool-like” to “game-like.” Arranging the systems in this manner allows for comparative evaluations of participant motivation with regard to tools, games, and IT artifacts that fall somewhere in between. In addition, this arrangement allows researchers to manipulate specific website elements to either direct participants to tools or games or allow participants to self-sort based on their individual interests.

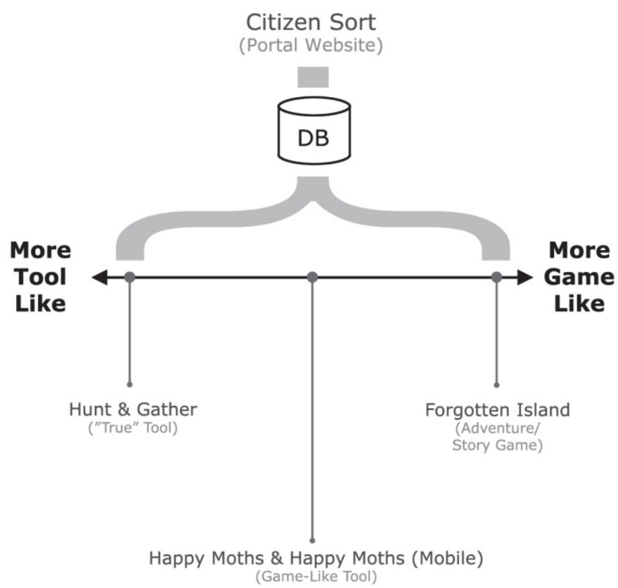

Figure 6.1. The *Citizen Sort* research design shows a theorized continuum from very tool-like instantiations to very game-like instantiations. Different user groups are hypothesized to be motivated by artifacts in different places on this continuum based on their personal goals, expectations, and interests vis-a-vis citizen science.

Four of the major artifacts of this design effort are organized around a fifth, a portal website (*Citizen Sort*) designed to direct participants to a variety of tools and games for biological classification. The portal website controls global functionality, including features like user-account management, administrative management of tools and games, content management of the website itself, dissemination of project data, and management of subsidiary projects. A centralized database ties all IT artifacts in this project tightly together.

3.3.2. Artifact 2: Hunt & Gather

Hunt & Gather is a "true" tool, designed without additional motivational elements (see Zhang and von Dran (2000) for a discussion of motivators vs. satisfiers in web applications). *Hunt & Gather* lets users create characters and states for themselves, tag large numbers of photos with those characters and states, and let other knowledgeable individuals work with the characters, states, and photos on a per project basis.

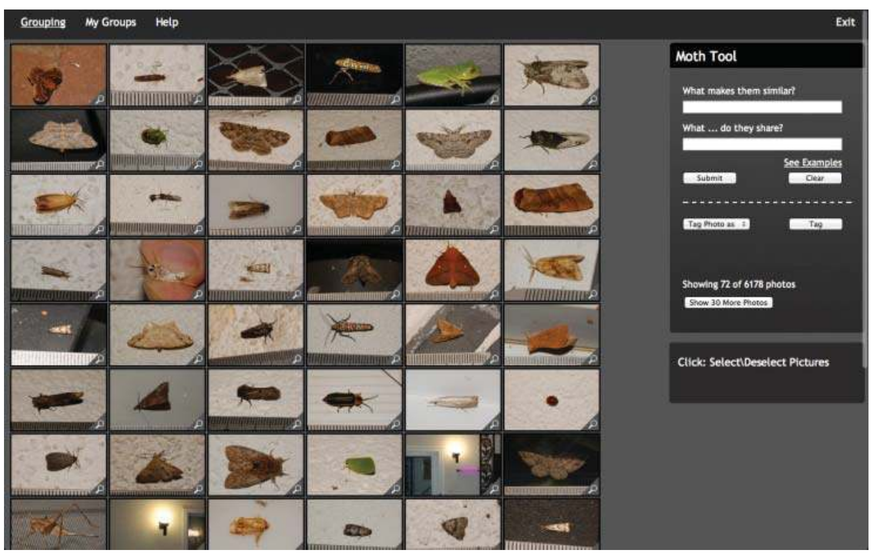

Figure 6.2. *Hunt & Gather* classification tool. Users can set up a collection of photos and work together to develop a taxonomy of characters and states.

Hunt & Gather will allow socio-computational researchers to explore the motivations of users who are attracted to citizen science tools, rather than games; it is hypothesized that these users will be experts or enthusiasts. Furthermore, characters and states created by novices or enthusiasts can be compared to characters and states generated by professional scientists. *Hunt & Gather* will help explore how good non-expert users are at producing characters and states that might be useful to experts in the biological sciences.

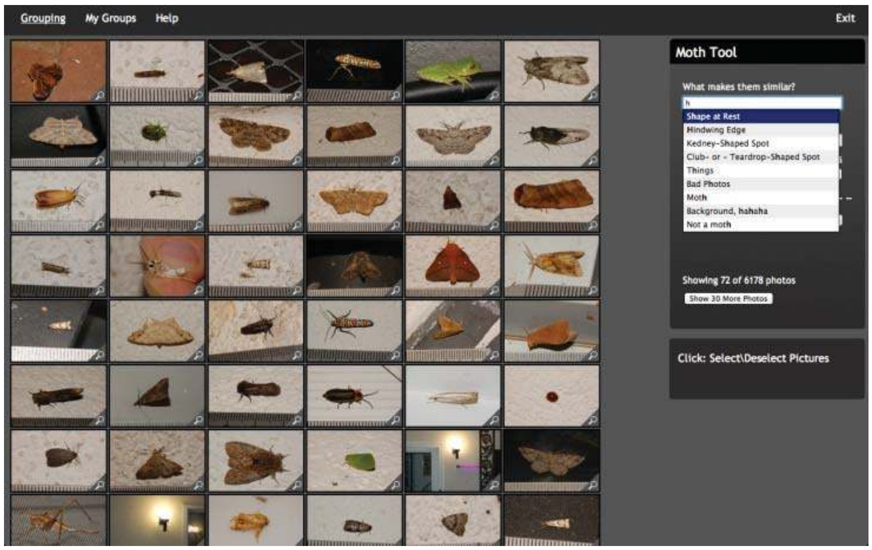

Figure 6.3. *Hunt & Gather* allows a group of users to collectively develop and refine taxonomies for a given collection of photos. Drop-down suggestions keep users informed about the characters and states that have already been defined. Pre-set choices for bad photos can be used to filter unwanted images from the collection permanently.

3.3.3. Artifact 3-4: Happy Moths & Happy Moths (Mobile)

Happy Moths (designed to be renamed for each new instantiation: *Happy Sharks, Happy Plants, etc.*) is a "game-like tool," in that it offers tool-like functionality but structured as a game. Participants are presented with a set of ten photographs of some organism (in *Happy Moths*, pictures of moths) and then asked to identify the various character-states of each. One difference between *Happy Moths* and *Hunt & Gather* is that the design aims to increase participant motivation by providing a score (per round and overall) giving feedback on performance. *Happy Moths* players are scored based on how well their classification decisions match those of a previously classified-photo that is seeded into the game (the

"Happy Moth"). Because players will not know which photo is the Happy Moth until the end of each game, they need to do well on all photos to ensure a high score.

Figure 6.4. *Happy Moths* setup screen, where photos can be pre-sorted as bad images or as bad examples of the specimen of interest.

Figure 6.5. *Happy Moths* game round, where players are asked to answer a question (character) by dragging a photo to the appropriate answer (states).

A second difference is that *Happy Moths* is built around characters and states established by professional scientists as a useful taxonomic key. *Happy Moths* is a more controlled experience for users, and may ultimately produce more reliable data when used by novices or enthusiasts with limited classification experience. As well, the quality of a player's performance on the Happy Moth can be taken as evidence of their data quality, and agreement among classifications performed by different users on the same photo can be used as an indicator of data validity.

Happy Moths also includes a mobile version, developed as an HTML5 mobile app and deployable on a variety of mobile devices. The mobile version of the game is very similar to the web-based version of *Happy Moths* (both systems contain the same logic and draw upon the same API and database). *Happy Moths (Mobile)* will introduce mobile technology as a variable in comparative evaluation studies; it will be useful in exploring whether mobile technologies make this game seem more or less game-like to users and whether ubiquitous access will help attract participants. It can also be used to collect data about where, how, and by whom the mobile version of the game might be used, and it will be possible to compare the quality of data produced by players of the two versions.

Figure 6.6. *Happy Moths* score screen, where players receive feedback on their performance and rewarded for correctly classifying the hidden "Happy Moth."

3.3.4. Artifact 5: Forgotten Island

Finally, an important goal of this research is to explore the full range of the “tool-like” to “game-like” continuum. Few citizen-science projects attempt to leverage the power of storytelling or fantasy in games to motivate users. In (T. Malone, W., 1980; T. W. Malone, 1982; T. W. Malone & Lepper, 1987), these elements and others are noted as key motivators in educational games; it is hypothesized that such motivators will hold true in citizen science games as well. To explore this hypothesis, as well as to generate insight into the kinds of users who might be attracted by such a game, the fifth IT artifact in this design-science project is a point-and-click adventure game called *Forgotten Island.*

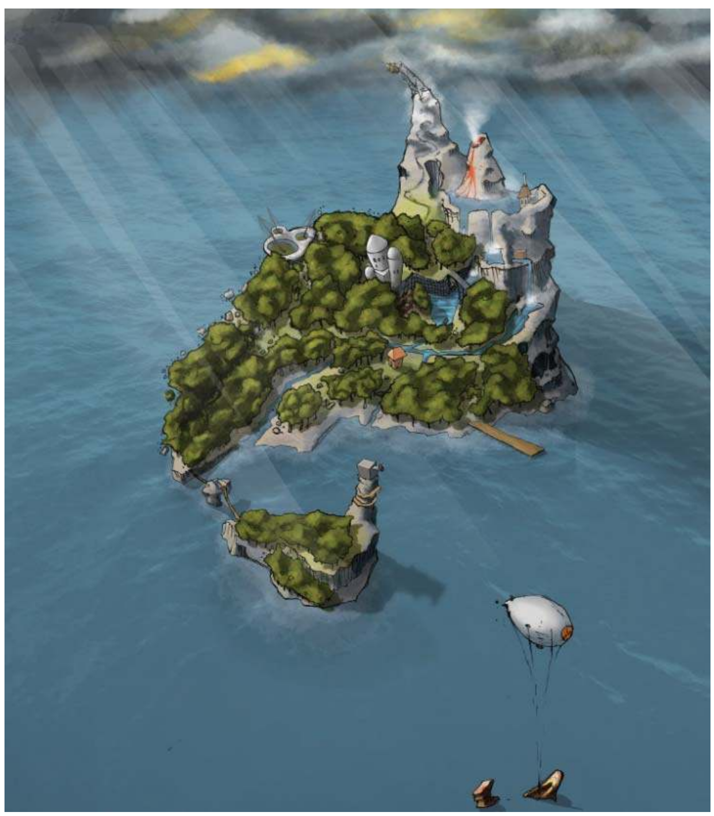

Figure 6.7. *Forgotten Island's* game world is a mysterious island that the player explores and rebuilds while undertaking citizen science classification tasks. The game world was deliberately designed in a hand-drawn style to accentuate that exploring will be a fun, engaging, and whimsical experience for the player.

Figure 6.8. The game world is made more mysterious and detailed through immersive, explorable locations. Unlocking these locations and advancing the story requires in-game tools and equipment that can only be acquired by undertaking the classification activity to earn game resources.

Figure 6.9. In *Forgotten Island*, the game story motivates the classification task. Story elements are conveyed to players through a comic book style interface.

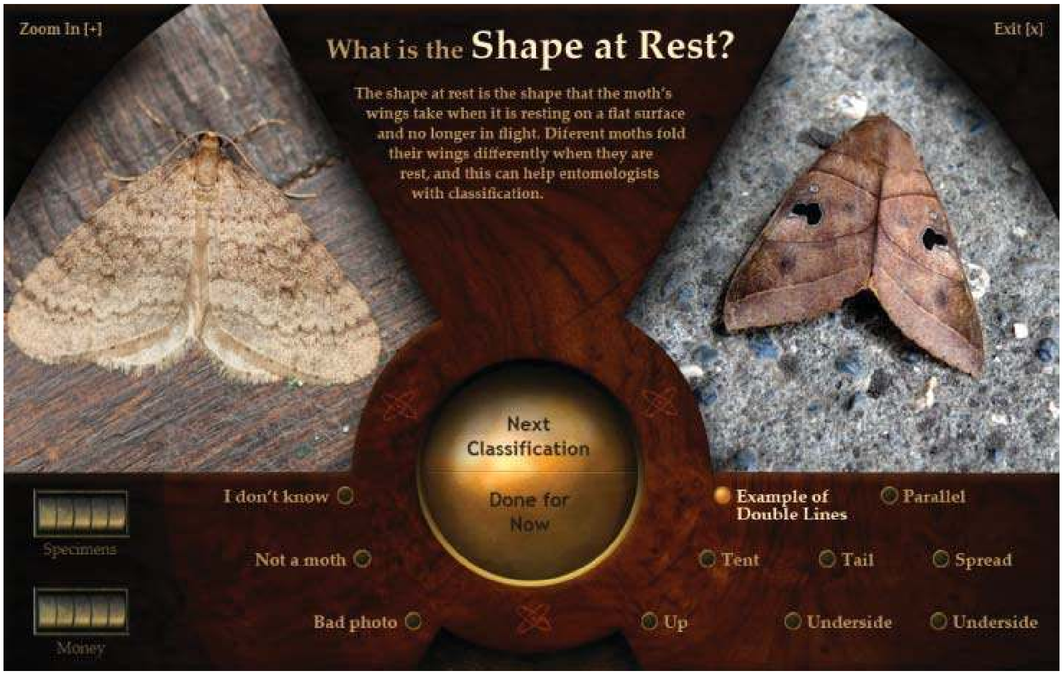

Figure6.10. The classification task itself is similar to *Happy Moths*. Key differences include that players in *Forgotten Island* classify one photo at a time to preserve a better balance between game experience and science experience, and that classifications earn the player endogenous rewards (game money) instead of feedback on their scientific contributions and point-based scores in competition with other players.

Forgotten Island is story driven, featuring an island to explore and a mystery to unravel. Players still classify insects, plants, or animals as in *Happy Moths*, but the classification task is motivated by the story and designed to fit into the background texture of the game. Players use classification as a way to earn game money that can be used to purchase equipment or items to progress the fantasy story.

Forgotten Island allows us to explore how endogenous reward systems can motivate players to participate in a scientific collaboration. It will also help explore how established taxonomies of motivational game features for learning (e.g. T. Malone, W., 1980; T. W. Malone, 1982; T. W. Malone & Lepper, 1987) might apply to non-educational games. Two additional and conflicting hypotheses will be evaluated: 1) that a fantasy adventure game will improve scientific data quality because players will be immersed in the game experience, motivated, and willing to provide high quality data, or 2) that a fantasy adventure game will reduce data quality because players will be more interested in progressing the story than in doing science, and will be willing to “cheat” on the science task to get ahead in the game.

4. Evaluation Method

Prior to starting system development, background research was conducted in the form of literature review, analysis of ongoing citizen science project systems, and SME interviews. Ten SME interviews with nine scientists and developers who are currently undertaking citizen-science projects were conducted. This phase of the project informed research questions and planning for the IT artifacts to be developed, and is reported in more detail elsewhere. As design progressed, additional SMEs were consulted, including naturalists with expertise in classification. Consultation with experts is ongoing, shifting between formal, interview-style consultation and informal participatory-research approaches (DeWalt & DeWalt, 2002).

This research is in now the design stage, with limited formal evaluation so far. In design science, however, design activities are a central aspect of research and are a vehicle for producing new knowledge. Accordingly, we have developed an evaluation strategy that includes some evaluation activities that take place during design. Individual developers working on the project have been asked to periodically review the games and tools where they have had a central development role, as well as games and tools where they have not been as directly involved. These reviews focus on the artifact itself, rather than individual work practices. Currently, 31 reviews have been collected on three of the five projects (*Happy Moths*, *Hunt & Gather*, and *Forgotten Island*).

In addition, formal focus group evaluation sessions have been conducted, targeted at two different versions of *Happy* Moths. An early focus group session brought four expert entomologists together codify their knowledge of the classification task and to collect their impressions of an early prototype of the *Happy Moths* game. Results from this session resulted in several changes to the game. Participants in a second set of focus groups were students as a large university located in the northeastern United States. Five participants were recruited from an outdoor club and environmental conservation courses, while three were recruited from the university's School of Information Studies. These groups were classified as “nature” and “gamer” participants respectively. Participants were asked to play a new version of *Happy Moths* and provide their opinions on two different visual designs: a “gamer” version designed to look more like a video game, with no naturalistic visual motifs other than the classification photos themselves, and a “nature” version designed to appear more tool-like while showcasing a variety of nature imagery and content.

5. Preliminary Results & Discussion

5.1. Participant Groups

During the first *Happy Moths* focus group session, SMEs helped to define three groups of potential participants who will be important for this research: 1) experts (professional scientists), 2) enthusiasts (individuals with intrinsic interest in science and/or the particular topic of a citizen science project), and 3) gamers (ordinary citizens with no particular interest in citizen science, but at least some interest in online games or entertainment). Because it may be difficult for some projects to attract enough expert and enthusiast users to be viable (especially those lacking "charismatic science" that is inherently interesting to many people), the gamer user group is of particular interest. The gamer group is hypothesized to be much larger than the enthusiast or expert groups, making it a potentially valuable source of participants. However, the gamer group, by definition, is composed of individuals who have virtually no knowledge of scientific classification. Finding ways to make the classification task enjoyable and, critically, understandable to these users will be an important outcome. One way of addressing this challenge, used in *Happy Moths*, is to have SMEs generate character questions and state answers that make sense to laypeople. So, for example, *Happy Moths* asks about simpler character-state combinations such as color or shape, and avoids complex questions about "discal spots," orbicular spots," "reniform spots," etc. In many cases, technical language has also been simplified to help lay users understand characters and states without the need for extensive training. In the *Happy Moths* focus group, SMEs had conflicting opinions about these approaches; some agreed that simplifying the tasks and language would be beneficial and still produce good data, while others felt that more technical nomenclature should be preserved as a learning opportunity for participants.

This disagreement raises another point about the differences between users: systems that motivate gamers may actually be de-motivating to enthusiasts and vice-versa. In the first *Happy Moths* focus group session, researchers suggested that systems designed to appeal to gamers (e.g., *Forgotten Island*) have a high likelihood of alienating enthusiasts. Enthusiasts are seeking opportunities to explore their passions and interests, while gamers are seeking entertainment. Over the course of design and evaluation so far, it has emerged that as a system focuses more on entertainment, it imposes increasing obstacles on enthusiasts who seek rapid access to their hobby of choice. For example, *Forgotten Island* paces the classification task and requires players to explore a variety of locations, collect items, and undertake many other story-driven activities besides classification. For an enthusiast interested in classification, these extra activities may be perceived as annoying wastes of time, rather than as engaging or fun. Similarly, SMEs frequently suggest that players will be more engaged and motivated if they learn something about science, but it is not clear that gamers will be similarly motivated.

5.2. The Role of Iteration

The purpose of taking each project in this design science study through several design iterations is threefold: each iteration 1) improves the IT artifact's ability to address the problem space, 2) produces new research findings, and 3) helps to eliminate poor system design as a confounding factor for research.

In the case of *Citizen Sort*, many specific design decisions have been discussed with the project's SMEs, particularly the decision-making that went into the *Happy Moths* game, which has (because it encapsulates the core classification task) received the most formal evaluation to date. Many design decisions have been upheld, while a few have been questioned (e.g., the visual style of *Happy Moths*, where expert reviewers suggested that a more "natural" or "nature-themed" design would better appeal to enthusiast users). In some cases, design decisions have been rejected outright. In the first iteration of *Happy Moths*, music was included, but focus group SMEs and the developers themselves unanimously rejected the choice to include music after testing it in several different settings. Now finishing its third and final iteration prior to public release, *Happy Moths* has no music and a streamlined game mechanic that is expected to be more fun and less distracting for players.

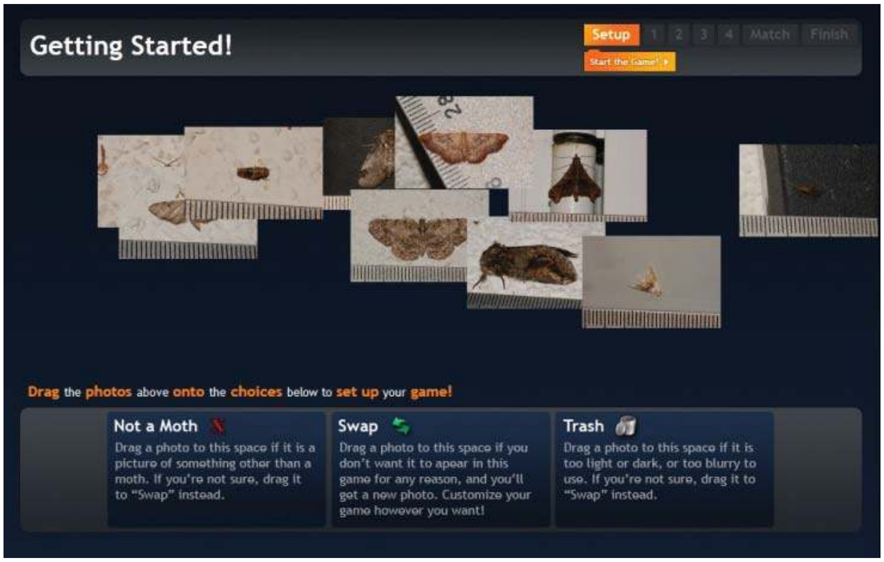

Figure 6.11. The "gamer" version of *Happy Moths* (version 2).

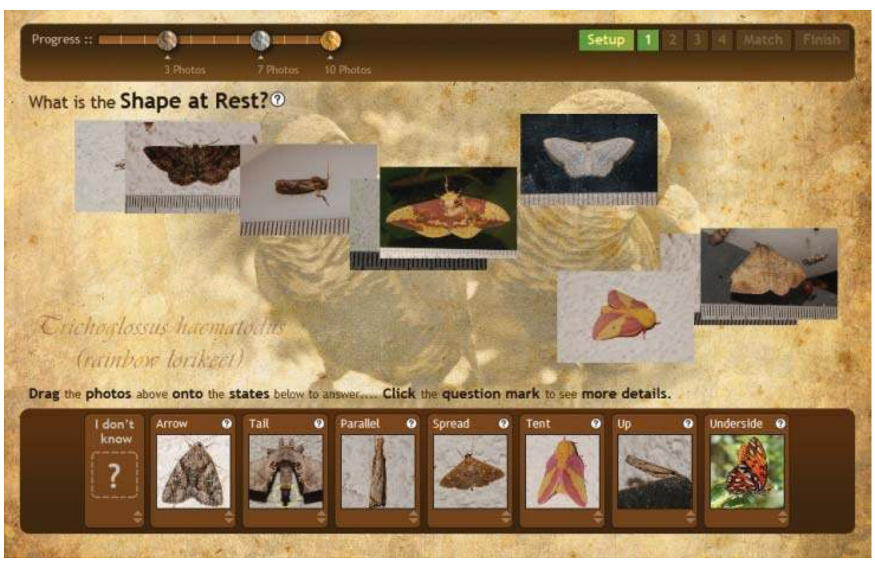

Figure 6.12. The "nature" version of *Happy Moths* (version 2).

The second round of *Happy Moths* focus groups were specifically designed to test another issue which came out of preliminary evaluation: the visual design of the game. Early visual workups used a contrasting color scheme of dark blue and bright yellow-orange. However, SMEs who are participants in our design partnership, as well as early focus group SMEs, suggested that this “gamer” design “did not emphasize nature enough.” Both groups of SMEs were composed of professional naturalists with enthusiasm for science and the outdoors; the blue-orange color scheme didn't speak to them as players. To explore this issue in more detail, second round focus group participants were asked to play one of two versions of the game: a version using the blue-orange color scheme and a functionally identical version using a nature-themed color scheme and nature imagery.

These focus groups revealed a mix of opinions on visual design. Both gamer and nature participants stated that each design was well conceived and visually attractive. In general, nature participants preferred the nature version of the game, while gamer participants preferred the gamer version. There was agreement that the nature version better supported the science task thematically, while the gamer version's contrasting color scheme made it easier to see and interact with the game space. Participants also agreed that the visual design was a less important issue than usability and how fun and engaging the game's scoring mechanic would be. These findings were very similar to opinions supplied by the development team during individual formal reviews.

We designed the third and final version of *Happy Moths* (see section 3.3.3) drawing extensively upon all of the previously collected evaluation data: focus groups (SME, gamer, and nature), participatory interactions with partner SMEs, developer reviews, and our own prior design experience (for a discussion of design precedent and design as an experience-based activity, see (Lawson, 2004, 2005)). Great attention was paid to the many perspectives espoused over the course of previous evaluations and design activities, resulting in a greatly polished, more engaging, and more usable game. More extensive evaluation of *Happy Moths* will take place over several months as the game is published online and played by participants as a live citizen science project. This "evaluation for research" (Dix, 2010) will help us to address our deeper research questions on socio-computational system design, motivation, and data quality. The evaluations conducted so far have already helped direct us toward several possible areas of interest.

5.3. Task Gamification vs. Game Taskification

Socio-computational and citizen science games are often developed by "gamifying" an existing task. The *Happy Moths* game adopts this approach, taking a classification task and adding game elements to it: a game-like visual design, scores for doing well, achievements for long-term involvement, leader boards, and high scores to promote competition between players.

The *Citizen Sort* project explores an alternative model, referred to here as "game taskification." In this approach, the typical model of turning tasks into simple games is inverted; rather, the designer starts with the game, rather than the task, designing an interactive entertainment experience and drawing upon well-understood commercial game design principles (e.g. Schell, 2008). Rather than simply re-conceptualizing a given task as a game-like activity (i.e. giving players game points for classifying a photo), the game designer must conceptualize the task as just one element or mechanic to be part of a larger (possibly *much* larger) game world. To be effective at generating data, the task must be incorporated in a way that makes it critical to progress through the game, but it need not be the focus of the player experience as it would be in a gamified task. For example, the scientific task might become a way of earning game money, a tool to power up one's character, a lock-picking puzzle, or a host of other possibilities.

The game-taskification approach opens up dramatic possibilities for purposeful games: exploring scientific content through unique themes and stories during play, building unexpected and exciting connections between entertainment and science, or engaging large segments of the population who may not be motivated by gamified tasks alone. However, the game taskification approach is rarely pursued in citizen science or socio-computational system design. Our design and evaluation process for *Forgotten Island* helps to explore one possible reason why not.

Simply put, turning a task into an enjoyable game is a complex endeavor. Developing a fantasy/story game like *Forgotten Island*, which “seduces” players into doing real science (Jafarinaimi, 2012; von Ahn & Dabbish, 2008) without foregrounding the task itself, is an exponentially larger effort than simply implementing the task. By placing the scientific task into the background of a fantasy game, developers are suddenly confronted with a host of new design requirements that are unrelated to the central rationale for designing the game (i.e., in the citizen science domain, collecting scientific data). These include developing a story and writing a script, creating locations, producing concept and final artwork, designing characters, envisioning and producing a compelling sound design, composing a musical score, programming complex functionality such as path finding or AI algorithms, planning and implementing puzzles, and more. In short, the research scientist must take on the role of game director, a role for which few are prepared.

Evaluations of *Forgotten Island*, which includes all of the above elements as design requirements, have underscored these challenges. During individual reviews, developers were asked to make an assessment of how complete they felt an evaluated system was. Developer reviews of *Happy Moths* and *Forgotten Island* conducted at approximately the same time during the development cycle (both in November, 2011) showed significantly different averages for this estimate. *Happy Moths* was evaluated to be 85.9% complete, while *Forgotten Island* was seen as being only 17.5% complete. This contrast in the remaining time to complete each game seems starker with additional information: at the time of review, *Forgotten Island* was still in its first iteration while *Happy Moths* was finishing its second design iteration and moving into its third (i.e., less complete than most developers assessed, but still much more polished than *Forgotten Island*). Currently, *Happy Moths* is nearing completion on its third and final version, while *Forgotten Island* is nearing completion of its first (and due to time and budget constraints, final) iteration.

Given the challenges of development, game taskification may or may not be as realistic an approach for designing citizen science games as better-understood methods of task gamification. A host of extra creative design activities can lead to longer development times and many more required resources. However, these costs may be worthwhile to incur if the end result is a game that is widely popular among the general public and produces a high number of classifications from each player.

The game economy of *Forgotten Island* rewards players with in-game currency for each classification that they complete, but also requires them to spend this money on items that are required to progress the story and finish the game. This makes it possible to balance the game economy by varying the reward amounts and item prices so that players must complete a specified base number of classifications in order to win. In its current balance ($50 reward per classification vs. between $250 and $750 cost for various items), *Forgotten Island* can be completed by a player who undertakes 183 classifications over the course of the game (assuming the player makes no classification mistakes and is also perfectly efficient in their purchases). *Happy Moths*, which adopts the gamified task approach, requires far fewer classifications for each "win" (either 5 or 10 classifications, depending on the number of photos in the game). So a player would need to play between 19 and 37 full games of *Happy Moths* in order to achieve the same number of classifications as one game of *Forgotten Island*. If the story and fantasy elements of *Forgotten Island* engage more players and engage them for longer than *Happy Moths* (as we expect; experiencing an interactive story should be a more compelling reason for many players to undertake classification than inherent interest in nature or science), then *Forgotten Island* may eventually seem a better investment despite the lengthy development cycle.

Even if *Forgotten Island* itself fails to produce very many classifications, it is valuable as a demonstration of the taskified game approach's potential to produce scientific tools that are also commercial entertainment products. One future possibility is to develop and release games like *Forgotten Island* for profit, supporting scientific research (as well as game development activities) through sales of the game. *Forgotten Island* itself will not follow this commercial model; it is a research prototype, developed without commercialization specifically in mind. However, as a model for the game taskification approach, it will be a useful vehicle for exploring purposeful games as commercial entertainment products, unique methods for developing such games, non-enthusiast motivations for participating in citizen science, and the impact that taskified games have on scientific data quality.

A third approach to purposeful game design is not part of our current *Citizen Sort* project, but bears mentioning because it offers interesting possibilities for future study. This approach is to turn a scientific or socio-computational task into a form of payment for play. Many casual games have successfully adopted a model where micro-payments unlock game items, new content, new game mechanics, or new levels of play. Substituting classification for cash payment could be an effective way to reward users for their help and attract gamers to a project, and this is one possible future direction for our research.

5.4. Friction

One complexity of the design science approach is the friction that generates through competition between problem space, research goals, and feasibility to develop the IT artifact. These factors each require tradeoffs among the others. In the *Citizen Sort* project, SMEs want to take ownership of a suite of games and tools to support a citizen classification effort. Their primary goal is that these should produce large amounts of very high quality data. Virtually all other considerations are secondary. From a socio-computational research perspective, however, the interest is in how different kinds of games or tools can motivate different kinds of users and produce different qualities of data. It matters less that each individual tool or game produce the best quality data or attract the right kind of users, than that each game or tool helps generate useful knowledge about the research questions of interest. This means that games like *Happy Moths* or *Forgotten Island* could produce extremely poor classification data but still be a research success in providing evidence of cheating effects or problems with the fantasy/story approach. This outcome would, of course, be considered a failure by SMEs.

In (Prestopnik, 2010), the need for multi-disciplinary expertise as well as expert developers on a design science project is noted, the better to adequately address both the problem space and research goals. Galison (Galison, 1997) describes how such collaborations can be difficult when friction between the varying goals of different interested parties develops. Galison describes the idea of "trading zones" (Galison, 1997) to accommodate the needs of various collaborators through a negotiating process. *Citizen Sort's* project manager takes a central role in these negotiations, coordinating various groups of SMEs and developers, ensuring that natural science and information science requirements are balanced, and verifying that the project scope is feasible for the development team. Our design efforts have validated "trading zone" efforts on this project, with research goals and the problem space largely complementing rather than conflicting with each other.

6. Conclusion

Design science is an approach to scientific inquiry where research goals are pursued through the development of an IT artifact positioned to address a real-world problem. This approach has many strengths, including the ability to tightly control research efforts while still enacting them within realistic use contexts. In addition, evaluation of design science efforts can address numerous research questions.

One constraint of design science is the friction that can develop between research goals, the problem space, and system feasibility. While good project management and careful attention to both researcher and stakeholder needs can mitigate these effects, friction is virtually impossible to eliminate entirely. Nonetheless, as the *Citizen Sort* project demonstrates, design science can be a valuable approach to exploring design issues in citizen science, purposeful gaming, and socio-computational system design.

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CHAPTER 7: Web Nuisances and Coping with Negative Emotions: Empirical Investigations and a Theoretical Model

By Nathan Prestopnik and Ping Zhang

Abstract

As a negative emotion, annoyance is a person's psychological state or feeling. Nuisances are objects in one's environment that can cause annoyance or other negative emotions to some people. In the online environment, just as in the physical environment, people encounter many nuisances. In order to effectively design and use ICTs and to ensure positive user experiences, it is important to understand what are considered web nuisances, how people react to them, and what can be done to either prevent ICT artifacts from being regarded as nuisances or to help people cope with annoyance and other negative emotions online.

This paper reports one of the first studies that systematically investigate web nuisances and strategies for coping with negative emotions. Given the scarcity of studies and findings in the literature, we first conduct two exploratory empirical studies to identify various web nuisance types and the ways users handle them. Then, drawing upon findings in the two empirical studies and psychological theories, we develop the Coping with Online Nuisance Encounters (CONE) model to depict the underlying psychological mechanism of online nuisance encounter and negative emotion coping. With theoretically justified propositions, the CONE model depicts a set of important concepts and their relationships that occur when web users encounter different kinds of web nuisances. This study has both theoretical and practical implications for online ICT design and use. It contributes to the

literature on investigating negative emotion elicitation and people's coping strategies, as well as specific ICT design strategies and guidelines.

1. Introduction

A *nuisance* is something that can cause one to have unpleasant feelings, or in particular, the feeling of annoyance. Just as in a physical environment, online environments such as the web can be full of nuisances. It is the rare individual who can avoid feelings of annoyance while navigating the World Wide Web. Pop-ups, interruptions, distractions, delays, and a host of other online nuisances, great and small, plague us as we seek and exchange information, conduct business, socialize, and entertain ourselves online.

So far, researchers have examined a variety of online nuisances and their impacts, as shown in the literature review section later. Yet, the findings are scattered and little attention has been devoted to developing a holistic understanding of the nature of online nuisances. In addition, few studies have focused on unearthing the underlying psychological mechanism that may help explain how people react to nuisances and how they cope with annoyance and other negative emotions.

In this study, we consider the web as the online environment. The web is an expansive domain, encompassing a great many genres of websites, hundreds of millions of users, and seemingly endless types of content. Nuisances of varying kinds are scattered throughout this sprawling wilderness, allowing us abundant opportunity to investigate nuisance related phenomena and gain insight on effective ICT design and use that minimize negative emotions and promote positive user experience.

Two important concepts in this study are nuisance and annoyance. Nuisances are things in one's surroundings that can cause unpleasant feelings in people, while annoyance is a person's particular negative feeling or an emotional state. These two concepts are related in that nuisances are the source of annoyance. They are different in that nuisances exist in the real world, but annoyance exists within a person (Zhang, forthcoming). Feelings of annoyance stem from interactions that occur between an individual user and a nuisance, not solely from the nuisance in isolation. Annoyance may disappear once the person is not faced with the nuisance, but a nuisance exists regardless of who may encounter it. It is important to note that some nuisances produce relatively insignificant and fleeting feelings of annoyance in some people, while other nuisances may generate prolonged and intense negative emotions beyond annoyance, such as stress, frustration or anger.

This study is intended to gain both theoretical and empirical insight on the online nuisance phenomenon. It has two objectives. The first is to understand what are considered nuisances by online users. Using a mixed method approach, we conduct two qualitative empirical studies to gather online users' opinions in different online settings. Combined with an extensive literature review, we depict various characteristics of nuisances, and thus provide a view of the online nuisance landscape. The second objective is to understand how online users react – behaviorally, cognitively, and emotionally – to nuisances when they are encountered. This understanding is represented by a theoretical model we propose: the *Coping with Online Nuisance Encounters (CONE)* model. This model is based on psychological theories on stress and reactance and our empirical results that highlight the significant contributing factors.

This paper is organized as follows. We begin with a review of the HCI literature to identify specific types of nuisances and their impacts. Then we lay the theoretical foundation of the online nuisance phenomenon by introducing two psychological theories. Following the theoretical section, we describe two exploratory empirical studies, a focus group and a survey, that we use to gain first-hand understanding of online users' opinions about nuisances. The findings of these studies extend our understanding from the literature, identify the important contributing factors in the phenomenon, and yield the construction of an online nuisance landscape. They also prompt the application of the two theories and lead to the development of the CONE model in the following section. In that section, we provide details of CONE by providing propositions that can help future empirical investigations on nuisance related phenomenon. We conclude with limitations, theoretical and practical implications, and potential future directions.

2. Literature Review

Several studies identified specific types of online nuisances and some also explored their impacts, effects, and outcomes. In this section, we explore and analyze such work.

2.1 Online Nuisance Types

Computer-related nuisances can exist in both online and offline environments. For example, Johansson and Aronsson (1984) specifically explored how interruptions, delayed computer responses, and other nuisances caused stress-like physiological symptoms in white-collar office workers. Hudiburg and Necessary (1996) similarly examined computer-related stress, showing that high-stress users typically employed different forms of coping than low-stress users.

Moving fully into the online environment, Bailey et al. (2001) investigated how task interruptions can be annoying and anxiety-causing, noting that users performed more slowly on interrupted tasks, perceived interrupted tasks to be more difficult, and had increased anxiety when peripheral tasks interrupted primary ones. Edwards, Li, and Lee (2002) further expanded this notion of interruptions to include pop-ups and interstitials.

Delays and download times are another well-covered area of study. Rose and Straub (2001) identified several technological impediments to e-commerce, including delay and download time, finding that delay might affect a user's likelihood of leaving a site or abandoning a download. Rose, Lees, and Meuter (Rose, Lees, & Meuter, 2001) validated and confirmed this finding. Similarly, Szameitat, Rummel, Szameitat, and Sterr (2009) examined delays in the context of modern computing and found that while delay times have significantly shortened over the years, users are still frustrated by even short wait times.

Passant, Kärger, Hausenblas, Olmedilla, Polleres, and Decker (2009) turned their attention to privacy issues, examining this broad topic from a practice-oriented viewpoint and identifying common privacy-related nuisances. Debatin, Lovejoy, Horn, and Hughes (2009) argued that safer use of social network services would require changes in user attitude, and Dwyer, Hiltz, and Passerini (2007) demonstrated that online relationships may develop even in sites where perceived trust and privacy safeguards are weak. Park (2009) examined privacy in the context of information system effectiveness and user satisfaction, finding that increased privacy concerns among users negatively impacted both of these outcomes. However, privacy-related nuisances are often perceived very differently by different users.

Animation has been studied as yet another source of annoyance online. Zhang (2000) explored the relationship of online animation to information seeking and task performance, finding that animation deteriorated performance in these tasks under various circumstances. Thota, Song, and Larsen (2009) showed that animated banner advertisements generated increased skepticism toward a website and the brand in the ad, while Hong, Thong, and Tam (2007) suggested that non-banner animation may attract users' attention, but also negatively impacts their task performance and perceptions.

Online advertisements are often thought of as a nuisance by many internet users. Various scholars studied how online advertisements impact the user experience. Cho and Cheon (2004) explored how advertising clutter can determine whether users avoid or ignore internet-based ads. Furthermore, they showed how many ads can also be perceived as impediments to user goals. Ha and McCann (2008) studied advertising clutter in both on- and off-line contexts, finding support for ad clutter and resulting loss of control as a motivator for ad avoidance (L. Ha, 1996; Louisa Ha & McCann, 2008).

2.2 Three Nuisance Dimensions

Most nuisance types described in the existing studies can be characterized along three different dimensions: content, form, and behavior. The content dimension is concerned with the message a nuisance carries (i.e. semantics). In many cases, the messaging or meaning was most annoying. This is common in advertising nuisances (Edwards et al., 2002), but can also exist in social media and other content-laden settings (Passant et al., 2009).

The form dimension is concerned with the presentation of the nuisance (i.e. syntax). For example, nuisances stemming from visual ugliness (Norman, 2004) or clutter (e.g. seeing the same advertisement too frequently) (Cho & Cheon, 2004; L. Ha, 1996; Louisa Ha & McCann, 2008) are considered annoying by many.

Finally, the behavior dimension concerns itself with how a nuisance acts (i.e. functionality). Pop-ups (Edwards et al., 2002), download times (Rose et al., 2001; Rose & Straub, 2001), delays (Szameitat et al., 2009), and animation (Zhang, 2000) all seem to have a behavior dimension: they are doing something or taking actions that annoy users.

2.3 Loss of Control

Most individuals go online in their privately owned home or residence on personal computers they own or have the right to use. Their normal expectation is to have control over this experience, just as they have control over other products that they own. Online, however, this is not always the case. Ownership of a computer system gives the appearance (and thus expectation) of control, but the networked nature of the web allows browsers and other computer software to take a variety of actions without the consent of the user. Many of the studies we reviewed showed how loss of control is related to various kinds of nuisances.

For example, the interruptions and pop-ups studied by Bailey et al. (2001) and the download delays described by Rose and Straub (2001), Rose et al. (2001), and Szameitat et al. (2009) all have a negative impact on users' control over their online experience. These various nuisances allow the computer system to take actions that are unwelcome to the user, sometimes preventing them from doing very much about it.

The same is true of privacy nuisances. Park (2009), quoting Stone, Gardner, Gueutal, and McClure (1983), defined privacy as, "the ability of the individual to control personal information about one's self," explicitly linking privacy violations to a loss of control. Debatin et al's (2009) argument for shifts in user attitudes regarding privacy and social networks similarly suggested a loss of control as the use of a technology requires users to change their preferred behaviors to something else.

Edwards, Li, and Lee (2002) and Ha and McCann (2008) frame their discussions of advertising clutter with Brehm's (1966; S. S. Brehm & Brehm, 1981) theory of Psychological Reactance. This theory describes how individuals are affected by losses of freedom and control. This theory seems potentially relevant to many other nuisance studies, but has not been adopted by them.

In summary, though certain nuisances were covered in the literature, there was no systematic exploration of nuisance types and no clear understanding of the underlying cognitive mechanism through which users react to online nuisances. Without such an understanding, guidelines to ICT design, use and management are limited.

3. Theoretical Foundation

In this section, we introduce two relevant psychological theories that provide the guidance of our empirical investigation and will lead the development of the CONE model. These theories address, respectively, the psychological impact of restrictions on control and the ways that individuals cope with stress.

3.1 Theoretical Base 1: Psychological Reactance

Psychological reactance theory describes how restrictions on freedom or control impact the psychological state of an individual (J. W. Brehm, 1966; S. S. Brehm & Brehm, 1981; Wortman & Brehm, 1975). This theory is notable in that Wortman, Brehm, and Leonard (1975) posited that, "uncontrollable outcomes can be theoretically equivalent to eliminations of freedom," and suggested that freedom should ultimately be defined as the "expectation of control."

In a given moment, individuals have the ability to choose from among a variety of possible courses of action. An individual's freedom of choice and control over these actions are limited to acts that are realistically possible; an individual only has a given freedom if he or she has *knowledge* of that freedom and the *ability* to exercise it. Taking a walk to the moon is not a freedom, but going outside and looking at the moon might be (J. W. Brehm, 1966; S. S. Brehm & Brehm, 1981). Individuals may expect to make various purchase or consumption choices (J. W. Brehm, 1966; S. S. Brehm & Brehm, 1981), freely hold certain viewpoints, for example political, moral, or religious beliefs, and they may expect to freely choose to participate or not in various events (Clee & Wicklund, 1980).

Psychological reactance occurs in an individual when his or her control is threatened or reduced. It is a motivational state wherein the individual will wish to reestablish lost or threatened freedoms (J. W. Brehm, 1966; J. W. Brehm & Cole, 1966; S. S. Brehm & Brehm, 1981). Brehm and Cole (1966) suggested that the amount or intensity of reactance is a function of four elements:

1. Whether or not the freedom was perceived to be held in the first place
2. How severe the effects of the loss of the freedom will be
3. How important the lost or threatened freedom is to the individual
4. How much the loss of this freedom will affect other freedoms

Brehm (1966) and others (Clee & Wicklund, 1980; Dowd, Milne, & Wise, 1991) indicated that, because psychological reactance is a motivational state, experiencing it will result in certain behaviors or emotions, termed reactance effects. Observable behaviors aimed at the restoration of threatened or lost control are the most obvious of these effects, but Brehm and Brehm (1981) also suggested that subjective (i.e. emotional and cognitive) responses are also possible. For example:

1. Individuals' desire for the threatened outcome may increase;
2. Hostility toward the agent threatening the freedom may increase;
3. Individuals may become more self-directed (that is, more focused on restoring lost freedoms);
4. Individuals may deny that a freedom or threat to it even existed; and
5. Individuals may work harder to preserve other freedoms.

The degree or intensity of psychological reactance and the resulting reactance effects will be moderated by the specific situation and context of the threatened freedom because psychological reactance is a highly contextualized, individual, and subjective state. In some circumstances, direct action to restore lost control will be possible and desirable, while in others it will not be. In all cases, subjective responses (changes in attitude or emotion) should occur (S. S. Brehm & Brehm, 1981).

3.2 Theoretical Base 2: Psychological Stress

In our literature review we saw that many computer-related nuisances can be linked to stress and negative emotions. Furthermore, in most literature, annoyance and stress are treated as analogues. Accordingly, we are interested in a second theory: the theory of psychological stress coping.

Lazarus's (1966) theory of psychological stress, appraisal, and coping describes how individuals encounter, appraise, and cope with stressful situations. This theory has been elaborated upon by a variety of psychologists over the years (e.g. Carver, Scheier, & Weintraub, 1989; Folkman & Lazarus, 1980, 1985; Folkman, Lazarus, Dunkel-Schetter, DeLongis, & Gruen, 1986; Folkman, Lazarus, Gruen, & DeLongis, 1986; Lazarus, 1966, 1968, 1993a, 1993b, 1993c; Lazarus & Folkman, 1984; Lazarus & Launier, 1978; Skinner, Edge, Altman, & Sherwood, 2003; A. A. Stone & Neale, 1984).

Psychological stress is the result of an unfavorable individual-to-environment relationship. It can be the result of extremely unfavorable conditions, such as the death of a loved one, or of less serious conditions, such as anxiously waiting for exam grades (Lazarus, 1966, 1993b; Lazarus & Folkman, 1984). Individuals deal with psychological stress through a three-step process of primary appraisal, secondary appraisal, and coping. This process is a balancing act between the “demands, constraints, and resources of the environment,” and the, “the goal hierarchy and personal beliefs of the individual” (Lazarus, 1993b).

During primary appraisal, individuals differentiate between benign environmental conditions and environmental conditions which are potentially harmful. Such evaluations can be described in terms of “harm/loss,” “threat,” and “challenge.” Harm or loss is a damage which has already happened, for example injuries or loss of self-esteem. Threats constitute potential harms and losses. Challenges are opportunities for growth, mastery, or gain: stressful, but potentially positive in outcome (Folkman, 1984; Lazarus, 1993a). Primary appraisal is subjective, predicated on an individual's internal demands (personal desires or requirements that the environment must meet) as well as external demands (requirements placed upon the individual by the environment) (French, Rodgers, & Cobb, 1974).

Secondary appraisal is the process by which individuals determine responses to unfavorable individual-to-environment relationships (Lazarus, 1966, 1993b; Lazarus & Folkman, 1984). Responses are appraised in light of “physical, social, psychological, and material” assets that may be brought to bear in a given, specific situation (Folkman, 1984). Common response alternatives such as altering the situation, distancing oneself from it, or accepting it may be appropriate or possible in some situations while inappropriate or impossible in others (Folkman, Lazarus, Dunkel-Schetter et al., 1986).

Coping is the culminating activity of primary and secondary appraisal. During coping, individuals execute an appropriate response to the perceived environmental threat, attempting to master, reduce, or tolerate the internal and/or external demands that are created by the stressful transaction (Folkman, 1984). Coping can be emotion-focused or problem-focused. More typically, it is a combination of the two. Emotion-focused coping regulates emotion and distress, while problem-focused coping attempts to directly address or manage the problem causing distress (Folkman, 1984; Lazarus, 1966, 1968, 1993b; Lazarus & Folkman, 1984; Lazarus & Launier, 1978). For example, a student who is experiencing stress because of an upcoming exam might alter environmental conditions by studying harder, a problem-focused strategy. On the other hand, a student who has already taken the exam and is experiencing stress in anticipation of a poor grade might downgrade the exam's importance and avoid thinking about it, an emotion-focused strategy. According to Lazarus, threats that we avoid thinking about, even if temporarily, don't bother us (Lazarus, 1993b).

Aspects of both emotion-focused and problem-focused coping have been identified through many years of empirical and theoretical research (e.g. Carver et al., 1989; Doron, Stephan, Boich, & Le Scanff, 2009; Folkman & Lazarus, 1980, 1985; Folkman, Lazarus, Dunkel-Schetter et al., 1986; Folkman, Lazarus, Gruen et al., 1986; Lazarus, 1964, 1968; Lazarus & Alfert, 1964; Skinner et al., 2003; Speisman, Lazarus, Mordkoff, & Davison, 1964; A. A. Stone & Neale, 1984). Lazarus and others tested subjects under various stressful conditions (Lazarus & Alfert, 1964; Speisman et al., 1964) and requested information from participants about the types of stress they encountered and the ways they coped with it (Carver et al., 1989; Skinner et al., 2003; A. A. Stone & Neale, 1984). The culmination of this work has been the generation of the ways of coping checklist (Folkman & Lazarus, 1980, 1985), an instrument to measure and describe coping strategies. Variations and alternatives to this measurement exist (e.g. Carver et al., 1989; Skinner et al., 2003; A. A. Stone & Neale, 1984), but all essentially attempt to categorize various coping strategies, for the most part either implicitly or explicitly around the emotion/problem-focused structure.

The checklist identifies eight different methods of coping, including one problem-focused method of coping, six emotion-focused methods, and one mixed method (Folkman & Lazarus, 1985):

1. Problem Focused Coping (analyze and understand the problem, make a plan of action)
2. Wishful Thinking (wish to change what is happening or how one feels)
3. Distancing (try to forget, wait to see what will happen before acting)
4. Emphasize the Positive (look for silver linings, look on the bright side)
5. Self-Blame (criticize or blame oneself)
6. Tension-Reduction (try to make oneself feel better though eating, drinking, exercise, etc.)
7. Self-Isolation (avoid being with people, hide problems from others)
8. Mixed (seek support from others, accept sympathy and understanding)

4. Empirical Investigations of Nuisance Types and Users' Coping

Given the scarcity of online nuisance investigations, especially using the above two theories as guidance, we decided to conduct two empirical studies to gain some firsthand understanding on what consumers think about online nuisances. We adopted the mixed methods approach (Johnson & Onwuegbuzie, 2004; Wu, 2012), where qualitative and quantitative approaches are undertaken concurrently. We used two separate studies to triangulate and to expand. The first study was very exploratory, while the second deductively built upon the knowledge we gained in the first. In both studies, qualitative approaches were dominant, and quantitative analysis was limited to basic descriptive statistics such as frequencies and percentages.

Both studies relied heavily on consumers' verbal expressions. The objectives of these empirical studies were consistent with our overall objectives of the study. In particular, we aimed at (1) depicting the online nuisance landscape based on consumers' comments, and (2) exploring the process of reacting to nuisances by identifying highly mentioned factors that may be aligned with our theoretical bases.

4.1 Methods and Procedures

4.1.1. Study 1: Focus Groups

In order to gain broad representation of web site types and user population, we constructed two focus groups: the first had eight full time staff members, and the second five full time students, all from a private university in the northeastern United States. In both groups, we asked participants to respond to two websites: *Facebook* (a prominent social media website) and *MySlice* (a web-based enterprise resource system). Among the 13 participants in total, 85% were female, 54% were married, and the ages ranged from 22 to 58. At the time of the empirical study, participants had been users of *Facebook* from two months to six years, and had been using it from "a few times per month" to "several times per day." They had been users of *MySlice* from two months to nine years, and had been using it from "rarely" to "several times per day."

Each focus group meeting lasted for approximately 45 minutes. Participants were prompted with the following five questions during the meeting: (1) What are the three *Facebook* features that annoy you? What specific aspects of these features annoy you? (2) Why haven't the nuisances made you avoid or stop using *Facebook*? (3) What kinds of nuisances would make you avoid or stop using *Facebook*? (4) What are the three *MySlice* features that annoy you? What specific aspects of these features annoy you? And (5) What would make you use *MySlice* more or avoid it less?

The two focus group meetings were audio taped, transcribed, and content analyzed. Participants' responses could be classified into four broad types: (1) describing and evaluating website/application (their features and their characteristics), (2) describing and evaluating the third parties to the websites, (3) describing and evaluating other people's online behaviors, and (4) describing and justifying what they would do when facing online nuisances while using *Facebook* or *MySlice*.

The first three types of responses are all about nuisances (different objects or sources as nuisances) and were content analyzed with a hybrid of deduction and induction. For our deductive analysis, we used the content-form-behavior framework from the literature review to classify participants' comments. For our inductive analysis, we formed codes based on participants' specific words/phases and groupings of them.

The fourth type of response is about the ways people react to nuisances on the web and how they deal with them. These responses were content analyzed using deductive codes generated from our theoretical bases.

Though Study 1 was both exploratory and highly interpretive, we used basic percent agreement calculations to ensure a degree of reliability in our codes. Three researchers finalized the coding based on the final coding scheme and achieved 95% agreement after discussion and mediation.

4.1.2. Study 2: Online Survey

For our second study, we used an online survey to collect web users' responses to one particular yet very popular web nuisance: web advertisements. Our intention was to confirm our findings from Study 1 and continue to evolve our understanding of the online nuisance landscape and people's reactions.

Study 2 data is part of a larger project on examining consumers' reactions toward online ads. Through Amazon Mechanical Turk (AMT), 261 individuals in the US responded to an online survey and were awarded micro-payments for completing tasks with quality. We selected AMT as a dissemination mechanism because it is a reasonably good approach for reaching a broad cross-section of the web-using public (Berinsky, Huber, & Lenz., 2011) and because it returns high quality results quickly (Ipeirotis, 2010). Slightly more women than men participated (55.6% women, 44.5% men), and survey respondents were predominantly Caucasian (73.6% Caucasian, 8.8% Asian/Pacific Rim, 5.7% African American, 4.6% Hispanic, and 7.3% other). 88.1% of respondents were originally from the United States, while 11.9% were originally from other countries. Respondents held a wide variety of occupations and were widely dispersed geographically, though most lived in the United States. Education levels were also widely varied (28.7% high school, 16.9% associate, 38.7% bachelor, 11.1% Master's, 2.7% doctoral).

Participants were asked the following open-ended questions: (1) What is the most negative ad you have encountered? (2) What are the top three reasons it is the most negative? (3) What did you do when facing negative ads? (4) Any additional comments regarding negative ads?

Participant responses were content analyzed and again fell into four categories, slightly different to the four category breakdowns in Study 1: (1) describing and evaluating advertisements themselves (their features and their characteristics), (2) describing and evaluating the advertised products and services (what the advertisements were about), (3) describing the host website (the website where the advertisements appeared), and (4) describing and justifying what they would do when facing online advertising nuisances.

Content analysis took place through a hybrid of deductive and inductive means. For response types 1-3, our deductive analysis used the content-form-behavior framework from the literature review to classify participants' comments. Our inductive analysis started out deductively using the various nuisance codes from Study 1, but these were adjusted based upon our read of the Study 2 data. For responses about reacting to and dealing with nuisances on the web, we used deductive analysis and generated from our theoretical bases.

Study 2 is also exploratory in nature. To ensure some degree of reliability in our interpretation of the data, we calculated a basic percent agreement between two coding partners, one of whom coded the entire data set while the other sampled approximately 50% of the data. Using this method, the overall intercoder reliability was 93%. At the individual code level, all agreements were calculated above 80%.

4.2 Results on Nuisance Landscape

In this section, we report our findings on the nuisance landscape. The next section focuses on how people react to nuisances.

4.2.1. Study 1

Tables 1 and 2 summarize our findings of identified nuisances that are broadly categorized into two types: (1) designed features of the nuisances themselves and (2) evaluations made by users about some nuisances. The first columns of the tables list inductively developed codes based on the focus group discussions. We developed the codes by grouping similar participant statements. For example, the code "confusing" covers a variety of situations when our participants indicated their confusion (plus annoyance) at something in *Facebook* or *MySlice*. The numbers are frequency counts, and an example statement is also shown. Among all comments on nuisances, the majority (101 out of 135 or 75%) were about the specific website, while 13% each were about third parties or other people.

Designed Nuisance Features	Total	FB	MS	Staff	Students	Sample Excerpts
Parts of Website that Annoy	**51**	**18**	**33**	**24**	**27**	
Website Performance	16	1	15	9	7	*"Yea, because even if you type in the correct course number, half the time it wouldn't show up"*
Appearance	13	3	10	6	7	*"I think that the look and feel and functionality of MySlice is very dated. It's like early 2000's or late 90's type of development and it's horrible. It's horrible looking."*
Instigates User Action	11	5	6	4	7	*"I have to acknowledge in some way that I have received the poke, or if I need to poke back. I need to download things on your computer. It just takes up too much time."*
Complexity	6	4	2	2	4	*"It's just a dashboard with a million things thrown in your face at once."*
Customization	2	2	0	1	1	*"Something like that would really, really annoy me: customizable profiles, pop up advertisements. Every time you looked at somebody's profile some song would blast out…"*
Financial Consequence	2	2	0	1	1	*"Having to pay. That would be my limit, I don't like paying for things."*
Compatibility	1	1	0	1	0	*"I think if they stopped developing their mobile app I would stop using it [Facebook], because 90% of the time I use it from my phone."*
3rd Party Annoyances	**5**	**5**	**0**	**3**	**2**	
Instigates User Action	3	3	0	2	1	*"I don't like any of those kinds of things where you get the gifts and drinks... I feel bad if I don't respond to people when they do this to me."*
Appearance	2	2	0	1	1	*"And they [updates from 3rd party games] are physically large. Like they increase your scroll."*

Table 7.1. Designed nuisance features from Study 1 found in *Facebook* and *MySlice.* FB=*Facebook.* MS=*MySlice.*

Evaluations Made by Users	Total	FB	MS	Staff	Students	Sample Excerpts
Parts of Website that Annoy	**50**	**34**	**16**	**25**	**25**	
Confusing	20	10	10	10	10	*"Really? Well I don't know how to do that, so I just don't. I just ignore them all."*
Content Concern	16	10	6	8	8	*90% of the stuff that's on there I don't really care about to be honest... I don't really care that she [my daughter] put her sweatpants on at 2:20 pm on Saturday."*
Privacy Concern	9	9	0	3	6	*"I didn't have any pictures posted online, which is how I wanted it. But somebody posted a picture of me. They got to, I really don't know how it works. But all of sudden they are there. And I don't like the picture."*
Social Concern	5	5	0	4	1	*"Your crazy friends are posting notes to your page, and you're not monitoring that in any way"*
3rd Party Annoyances	**12**	**12**	**0**	**3**	**9**	
Content Concern	7	7	0	3	4	*"They [third-party games] are constantly populating your news feed. Putting a new item on your news feed that really you don't care about."*
Privacy Concern	5	5	0	0	5	*"Because a lot of them are third-party trying to get your information, which is kind of a privacy issue to me."*
People's Behaviors That Annoy	**17**	**17**	**0**	**10**	**7**	*"The same person has asked me to be their friend like three times, and I hit ignore every single time. Not because I don't have any interest, but I always feel bad every time."*

Table 7.2. Evaluations made by users in Study 1 about *Facebook* and *MySlice nuisances.* FB=*Facebook.* MS=*MySlice.*

The *MySlice* application was agreed by most focus group participants to be rather poorly designed and difficult to use (hence many instances of confusing design, poor appearance, and poor performance). On the other hand, privacy concerns were more common in *Facebook* than in *MySlice*. This is noteworthy; *MySlice* is an application designed specifically to allow university employees and students to manage vast stores of highly personal and private data such as grades, payroll information, insurance information, emergency contact information, and more. Participants clearly perceived a difference between *Facebook* and *MySlice* in the ways these applications handle private information. Despite overall dislike of *MySlice* because of its design, our participants had more positive perceptions about its privacy controls, probably because of the organizational structure and rules in which it is embedded. A user's expectations and understanding of the environment in which an online system will be used appear to be important factors when evaluating nuisances.

Comments about other people's behaviors were typical during discussions of *Facebook* (social interactions are not possible in *MySlice*). Behaviors of friends, as opposed to those of families or colleagues, were frequently described as *Facebook* nuisances, suggesting that particular categories of acquaintance may be more likely to cause annoyance than others. The activity of family members appeared to be less annoying overall than the activity of friends. However, participants who identified excessive customization as a form of annoyance, also indicated, somewhat contradictorily, that the ability to customize was a positive feature. Customization seemed to allow *Facebook* users to "fix" nuisances caused by others:

> *"The nice feature is they just added 'hide applications' which, instead of just hiding people that use that stuff [third-party games which send updates from other users] all the time, now you can hide the application itself."*

Granting users the ability to control the effects of other people's behavior seemed to be one way of reducing this cause of annoyance. At the same time, while customization gives users the ability to fix nuisances, this benefit can morph into a nuisance if customization begins to adversely affect the experience of others.

4.2.2. Study 2

In Study 2 we investigated a typical type of nuisances in another context: web advertising. We were interested in building upon, verifying, and expanding Study 1 findings to see how the nuisance landscape might change from context to context. Similar to Study 1, we coded our data inductively and iteratively for various kinds of nuisances. Note that our codebook changed from Study 1 to Study 2. The changed context (online advertising instead of social media or enterprise resource systems) and the knowledge gained from Study 1 motivated us to retain some codes while adding and changing others. For example, in Study 1, we used the code "content concern" to indicate when participants discussed various kinds of content that annoyed them. In Study 2, this code was replaced with more specific codes like "offensive," "irrelevant," and "deceptive." In Tables 3 and 4, the numbers are frequency counts and the percent of responses to which each code was assigned. As in Study 1, we categorized codes into two broad types: (1) designed features of the nuisances themselves and (2) evaluations made by users about nuisances.

Designed Nuisance Features	Count	Percent	Example
Get Rid of	71	27%	"It was hard to get rid of it, no close button."
Pop-Up	54	21%	"It pops up right when you're trying to concentrate on something."
Blocks Content	40	15%	"It was big and covered up what I was reading."
Audio	27	10%	"They're usually loud and always annoying."
Frequency	27	10%	"Same ad encountered all the time."
Size	24	9%	"Takes up too much space."
Performance	19	7%	"It is taxing to my computer and the browser. Often, these ads are Flash-based and make the whole web page load slower."
Animation	18	7%	"Fast moving to the point it was almost unreadable."
Appearance	16	6%	"It changes the proportion or scale of the website and is not pretty to look at."
Auto-Play	13	5%	"Auto-play ads are the worst. They are loud and often unexpected."
Malicious	11	4%	"One that carried a scripted object carrying an infection."
Video	11	4%	"The ad acts the same as a commercial on TV, which I do not want to have to watch when I am online."
Duration	4	2%	"The ad is usually more lengthy than it has to be."

Table 7.3. Designed nuisance advertising features in Study 2.

Evaluations Made by Users	Count	Percent	Example
Distracting	72	28%	"It was intrusive and broke my concentration."
Irrelevant	70	27%	"If I wanted to know about the product I would research it myself."
Deceptive	67	26%	"It used misleading information to get me to their goal."
Offensive	62	24%	"There should never be pornography on sites where kids go often."
Privacy Concern	22	8%	"They give out personal info to other businesses."
Waste of Time	16	6%	"The ad is not a good use of my time."
Confusing	5	2%	"Ad is confusing."

Table 7.4. Evaluations made by users about advertising nuisances in Study 2.

Table 3 shows how many advertising nuisances contain specific features that were created by a designer (either intentionally or unintentionally): videos that play automatically, pop-up behaviors, audio, appearance, etc. The nuisances appearing in Table 4 are evaluative, and whether or not they are annoying depends upon the user judging and experiencing them. They are not just inherently designed features of the advertisements. For example, an ad that some users find offensive may be perfectly acceptable to others; the use of one's personal information may be within acceptable limits to some but an egregious violation of privacy to others.

4.2.3. Content, Form, and Behavior Analysis of Study 1 and Study 2

We organized the data from Studies 1 and 2 into the content-form-behavior dimensions to gain more insight into the nuisance types. Recall that we identified these dimensions in our literature review as potentially useful for conceptualizing nuisances in the online environment. Table 5 shows the result, using codes from both studies. The numbers are cumulative frequencies from previous tables.

Nuisance Landscape			
Designed Nuisance Features	0 - Content	128 - Form	219 - Behavior
		31 - Appearance (S1:15 / S2:16) 27 - Frequency (S2) 27 - Audio (S2) 24 - Size (S2) 11 - Video (S2) 6 - Complexity (S1) 2 - Customization (S1)	71 - Get Rid Of (S2) 54 - Pop-Up (S2) 40 - Blocks Content (S2) 35 - Performance (S1:16 / S2:19) 18 - Animation (S2) 14 - Instigates User Action (S1) 13 - Auto-Play (S2) 11 - Malicious (S2) 4 - Duration (S2) 2 - Financial Consequences (S1) 1 - Compatibility (S1)
Evaluations Made by Users	238 - Content	25 - Form	174 - Behavior
	70 - Irrelevant (S2) 67 - Deceptive (S2) 62 - Offensive (S2) 25 - Confusing (S1:20 / S2:5) 23 - Content Concern (S1) 16 - Waste of Time (S2)		72 - Distracting (S2) 36 - Privacy Concern (S1:14 / S2:22) 17 - People's Behaviors That Annoy (S1) 5 - Social Concern (S1)

Table 7.5. Grouping nuisances from Study 1 and Study 2 by content, form, and behavior. S1=Study 1. S2=Study 2.

Keep in mind that we do not consider content, form, and behavior to be separate and mutually exclusive categories of nuisance. Rather, we perceive that content, form, and behavior describe three different characters or natures of online nuisances. Many nuisances can be characterized by more than one, and perhaps all three, of these dimensions.

Nuisances that can be characterized or described by their form appear to be largely the result of design. These nuisances are the result of decisions made by a designer, who can, in effect, determine how annoying the form of an online system will be through various design choices. On the other hand, the content dimension of online nuisances is more subjective and based on evaluations made by users. Content decisions made by designers will impact different users in different ways. For example, content that is irrelevant or offensive to some users may be relevant and reasonable to others.

Finally, nuisances that are characterized by their behaviors seemed most common among the three types, but manifested as a mix of designed features and user evaluations. For example, things that are hard to get rid of or pop-ups were almost universally despised by our participants. Distractions were similarly disliked, but what was distracting to one user could sometimes be welcomed by others. This evaluative element to behavior nuisances is especially noticeable with regard to privacy, where there is much disagreement over what constitutes inappropriate use of personal information.

Note that this does not mean that annoyance is the intended outcome of the form and behavior dimensions of a nuisance. Most designers avoid annoying their users. However they often create specific forms or behaviors out of a desire to attract a user's attention or fulfill business requirements that may stand in opposition to the user experience. Annoyance can also be an accidental outcome of designed features, for example, if features are poorly conceptualized and implementation.

Note also that content (in advertisements as well as in other online media) does not happen by accident; content choices are made by designers, just as forms and behaviors are. In many contexts, designers choose content that they hope will appeal to users. However, users may evaluate that content negatively against their own expectations, norms, goals, and interests.

In Study 2, we found examples of mismatches between participant expectations and online content. For example, adult and political content were frequently subject to negative evaluations based on a mismatch to user expectations and interests, as shown in Table 6.

Online Nuisances That Mismatch Users' Expectations, Values or Norm	
Content Type	**Excerpts**
Adult	"Other members of the household may see the ad that shouldn't." "Lacks common decency." "It seems rather seedy/raunchy." "Degrading to women."
Political	"Implies that my values are 'wrong.'" "It knew I was visiting a liberal-oriented website and deliberately posted an ad for a conservative candidate." "It bad-mouthed the opposing candidate." "Was in direct conflict with my political views." "Speaks to values that are not mine."

Table 7.6. Mismatches between online content and user expectations

We also found examples where the same user reacted differently to content in two very similar advertisements. For example, Table 7 shows that in each of the two advertisements, this same user was proactively contacted via email because s/he already owned one of the company's products.

Varying Expectations Held by the Same User	
Expectation 1	"I felt that it infringed on my privacy, you see I am a Ford owner, a 2009 model, so it feels like it is bad enough to get mail from Ford and wanting me to buy a new car, now the internet too."
Expectation 2	"I like to know what updates are going on, especially when it comes to laptops, which I happen to own a Dell laptop and am interested in looking for one in the future, it gives me some useful info."

Table 7.7. Two different reactions from the same participant to similar advertisements

We had little information about why this user would feel positively about one ad and negatively about the other. The amount of trust in each brand, interest in their products, the content itself, and many other factors could be at play. Understanding what people do with nuisances when they are encountered is an important aspect of dealing with this challenging problem.

4.3 Results on What People Do With Nuisances

In order to explore what people do when encountering nuisances, we relied on what the literature indicated: loss of control may generate reactance, and people may have different coping strategies. Accordingly, we examined the data from both studies to identify control, reactance and coping related evidence. For control restrictions and reactance, we examined the participants' responses to detect any direct or indirect mentioning or examples of them. For coping, we used the ways of coping checklist (Folkman & Lazarus, 1985) as a guide for codes.

4.3.1. Study 1

Table 8 summarizes the coding result for Study 1. It shows a variety of control restrictions. Reactance emotions were experienced less frequently, though we did found some indications. We did note how this evidence seemed to conform to the stipulations of reactance theory. Recall that *MySlice* is mandatory to use, while *Facebook* is voluntary;

losses of control were mentioned by our participants in both, but only in *Facebook* were these seen as restrictions on otherwise available actions. In *MySlice*, users perceived fewer freedoms to begin with and so experienced no reactance when their degree of control was impacted.

Reactance Codes	Total	FB	MS	Staff	Student	Example
Control Restriction	46	29	17	21	25	"I also have outside applications and games [listed as a nuisance]. Because a lot of them are third-party trying to get your information which is kind of a privacy issue to me. Sometimes they can even get your information because your friend has the application, because if your friends can see your information, the application can see your information."
Reactance	10	10	0	2	8	"You are right, I put my stuff on Facebook so my friends can see it, not advertisers. That was not the purpose. When I joined so I can connect with people in college before I went to college in my case. I wanted those people to see it. It was later on down the road a company decided that we will take the information that you want your friends to see and we will give it to advertisers."

Table 7.8. Control restrictions and reactance in Study 1

As shown in Table 9, participants mentioned several ways of coping when facing nuisances. They particularly gravitated toward problem-based coping (e.g. using application features to reassert control over their online experience and deal with nuisances by modifying the interface, changing settings, or hiding unwanted information). Three emotion-focused coping approaches were also found in the data: emphasizing the positive, distancing, and self-blame. These were used when problem-focused coping was not available or in addition to problem-focused coping.

Focus group conversations sometimes took on the character of group support and consultation, thus functioned as a mixed coping approach, where participants sharing common problems and solutions. This is reflected in the last row of Table 9. One participant went so far as to address the researchers directly:

> *"I don't know what you're getting out of this [addressed to the researchers], but this is very enlightening."*

There was no evidence in the data for emotion-focused coping through tension-reduction, self-isolation, or wishful thinking. We speculate that it may be possible that these coping approaches could occur in an online environment, but acknowledge that the relatively low-intensity nature of online annoyances makes them unlikely.

Coping Codes	Total	FB	MS	Staff	Student	Example
Problem-Focused	24	20	4	15	9	"If you hit it on the side you can change it back to the original like the way it was before"
Emphasizing the Positive	24	21	3	13	11	"I'm going to continue [using Facebook despite nuisances] because that's now one of my communication tools. All my family is on there. Everybody's posting their vacation pictures instead of emailing them…"
Distancing	12	10	2	7	5	"When I first started on Facebook, which wasn't that long ago, couple months ago maybe, less than 6 months ago, and, um, you know when you first [sign up] you go on it a lot. But the nuisances, you know, quickly made me go from, you know, maybe 5 minutes twice a day to 5 minutes once a day to once a week, and now I'm like a once-a-monther because 90% of the stuff that's on there I don't really care about."
Self-Blame	4	4	0	3	1	"I've got to figure out how to do that [create different groups in Facebook]"
Mixed	2	2	0	2	0	A: "Like, it's [MySlice] very slow, and having to sit and wait for all the information… like, it's frustrating to me. I don't know if I'm just impatient, but…." B: "It might just be that MySlice doesn't come up well on your computer." A: "Okay. It might be…." B: "Did you try, like, working around another site? Because that site might be fine, and then MySlice…."

Table 7.9. Coping in Study 1

4.3.2. Study 2

Table 10 shows the results for control and reactance. Similar to Study 1, more control related evidence was identified than reactance evidence. We also used the reactance literature to unpacking reactance further in Study 2 than we did in Study 1, finding three of the specific reactance effects predicted by Brehm and Brehm (S. S. Brehm & Brehm, 1981). These are summarized in Table 11.

Code	Count	Percent	Examples
Control Restriction	142	54.4%	"There was no way to skip it or avoid it and get to the actual content." "It disrupts my website experience - I have to stop and figure out how to get rid of the ad." "They [advertisements] are annoying when I am in the process of reading something else." "Invasive... you did not ask to see/hear it." "Has loud audio that is disturbing at work." "They may take your information without permission." "It is designed to make the user feel incompetent." "It forces you to take action for the ad when that is not what you came to the page for."
Reactance	66	25.3%	"I really hate popular things coming out like everyone liked it and you have to like it too." "It makes me not want to buy the product." "It made me mad at the thing being advertised. A simple banner at the top of the page would have been a much more positive experience."

Table 7.10. Control restrictions and reactance in study 2

Evidence for Reactance Effects	
Increased Desire	"For me it's privacy. If I felt it's [*Facebook*] getting too much of my information, I would leave...."
Increased Hostility	"If an ad annoys me I will not click on it even though I might be interested in the product. I will probably note the advertiser and go to a competitor." "They're almost always noisy as well, forcing you to turn the sound off on your computer if you need to stay on that page and can't just flee the damned thing"
Heightened Focus	"Then people create groups that say change *Facebook* back [in response to changed interfaces for new features]."

Table 7.11. Example reactance effects in study 2

Table 12 shows the results for coping. We assigned the problem-focused code only when respondents indicated that they actually took some action to resolve a nuisance. Participants frequently indicated that they wanted to take some kind of problem-focused action but the advertisement or website in question would not allow them to. These intentions are summarized under the intended problem-focused code in Table 12.

Coping Approach	Count	Percent	Example
Problem-Focused	58	22.2%	"I have to just move the ad to a corner if I can't figure out how to get rid of it."
Intended Problem-Focused	23	8.8%	"I don't know how to stop them and I never knew you could. There's not enough information given to a user on how to do this."
Distancing	23	8.8%	"Don't they realize that those big ads make people tune out?"
Wishful Thinking	20	7.7%	"If they made them easier to stop or at least mute it would be better."
Emphasizing the Positive	12	4.6%	"Although they may be slightly annoying once in a while, they do serve the purpose of allowing access to web content that you may otherwise have to pay for in other ways."
Mixed	2	0.8%	"Finally, I get to tell someone how annoying these ads are. Thank you."
Tension Reduction	0	0.0%	--
Self-Blame	0	0.0%	--

Table 7.12. Coping in Study 2

The most common coping approaches were problem-focused, followed by distancing, wishful thinking, emphasizing the positive, and mixed. No evidence was found for either tension reduction or self-blame. While problem-focused coping appears to have consistent importance across multiple online contexts, emotion-focused approaches seem to shift in importance. For example, wishful thinking was found relatively frequently in Study 2, but was not found in Study 1.

4.4 Summary of Empirical Investigations

There are two take-away messages from our empirical studies: improved (maybe not yet comprehensive) understanding of an online nuisance landscape and greater insight into the process of coping with online nuisances.

4.4.1. Online Nuisance Landscape

The two studies showed the complexity and richness of the online nuisance landscape. It is plausible to classify various online nuisances across different contexts and use scenarios by form, content, and behavior. In our data analysis, a general guideline emerged out of this classification: form nuisances are largely designed, content nuisances manifest subjectively, and behavior nuisances can be both. This guideline is useful for designers to have in mind; it implies that many of the most common online nuisances (behaviors and forms) can be eliminated or mitigated by making alternative design choices. At the same time, more sophisticated design choices and decisions on where/when to implement these design choices could help reduce more subjectively induced content nuisances. For example, tailored advertising content that shows users certain kinds of ads based on their feedback or personal information undoubtedly helps to eliminate many subjective content nuisances.

The second take-away message has to do with a set of identifiable factors as well as the connections that begin to draw a pathway through an online nuisance event, from first encountering the nuisance to doing something about it. In particular, the following highlights the factors and a potential process in coping with online nuisances.

4.4.2. Antecedents to Encountering Nuisances

We noticed that some nuisances appear to be designed, while some are a function of both design and individual factors of the users: their goals, expectations, abilities, and personalities. Both designed features and the characteristics of the user can be important antecedent factors.

4.4.3. Appraising Nuisances

Users see restrictions of their control as an important element of many nuisances, and many participants reported very negatively about these restrictions. Restrictions on control and resulting negative perceptions are critical aspects of appraising an online encounter as being annoying or not. How much control is felt to be lost and how negative the encounter is perceived to be are functions of antecedents: the designed features and the characters of the user.

4.4.4. Emotional States

Assuming an encounter is appraised as a nuisance, two emotional states result: negative emotions and feelings of reactance. Negative emotions make us feel stressful and annoyed, and we become motivated to change this negative emotional state.

4.4.5. Coping Plans and Approaches

Motivation to improve one's negative emotional state implies that some action will be taken: direct action to eliminate or mitigate the nuisance itself or else other techniques to change one's emotional state. In the next section, we clarify this process further by presenting the CONE model.

5. Theorizing the CONE Model

In constructing the CONE model, we were faced with a dilemma of being parsimonious or being comprehensive. A parsimonious model has the advantage of being easy to understand and use, though it also has a limited ability to explain the entirety of a phenomenon. As a first step toward a theoretical understanding of the online nuisance phenomenon, we opted for a parsimonious model where we could capture significant factors and omit less significant ones.

Two psychological theories, reactance theory and the theory of psychological stress coping, provide general guidance for many situations, including situations occurring in the online environment. The CONE model combines these two theories and applies them specifically to fit the online environment. For example, not all factors in the two theories are relevant or significant in the online environment. Brehm and Cole (1966), for example, suggested that the amount or intensity of reactance is a function of four elements. In our empirical studies, it seems that the first element – whether or not a freedom was perceived to be held in the first place (which could be rephrases as perceived restriction) – stood out as a significant contributing factor among all four. The other factors were occasionally mentioned or identified in our empirical studies, but the frequency was so low that their significance could be projected to be much less than that of the first element. A similar situation is true of reactance. According to the reactance theory, there can be a number of emotional or attitudinal subjective responses to a restriction of freedom or control. In our empirical studies, not all of these were mentioned or mentioned equally, leading us to focus only on highly mentioned ones.

5.1 Overview of the CONE Model

Online nuisance encounters represent unfavorable individual-to-environment relationships because they result in a loss of control for the user. Restrictions on control result in annoyance (a form of stress and a type of negative emotions) and reactance (a motivational state). Users who encounter online nuisances will experience negative emotions about the online environment and seek to eliminate their negative emotions by either restoring their lost control or emotionally accommodating its loss.

The CONE model combines the two psychological theories so that the reactance theory is used to explore restrictions on control by considering antecedent factors to an individual's perceptions of a nuisance in the primary appraisal process and the psychological stress theory is used to explain the remainder of the appraisal and coping process. The CONE model is built on the idea that the reactance and psychological stress coping theories can each explain different phases of the same phenomenon – identifying and dealing with losses of control that manifest on the web - thus provide a complete process of online nuisance interaction and annoyance coping. In a nutshell, the CONE model consists of eight concepts and three main processes that arise during an interaction episode between an individual and an online nuisance. *Individual factors* and *online nuisances* are antecedents to primary appraisal, which generates a *perceived restriction* and *perceived negativity*. The individual then experiences psychological states *reactance* and *negative emotions*, which leads to a secondary appraisal to determine *planned actions* to be taken toward online nuisances and *subjective responses* regarding the psychological states. Two additional processes may occur upon taking planned actions or subjective responses, thus making iterations among the main processes. Upon taking planned actions, the individual iterates the primary appraisal that may yield changed perceived restriction and perceived negativity. Upon taking subjective responses, the individual re-experiences changed states. Figure 1 depicts the CONE model. Detailed definitions of the concepts and their relationships are provided below.

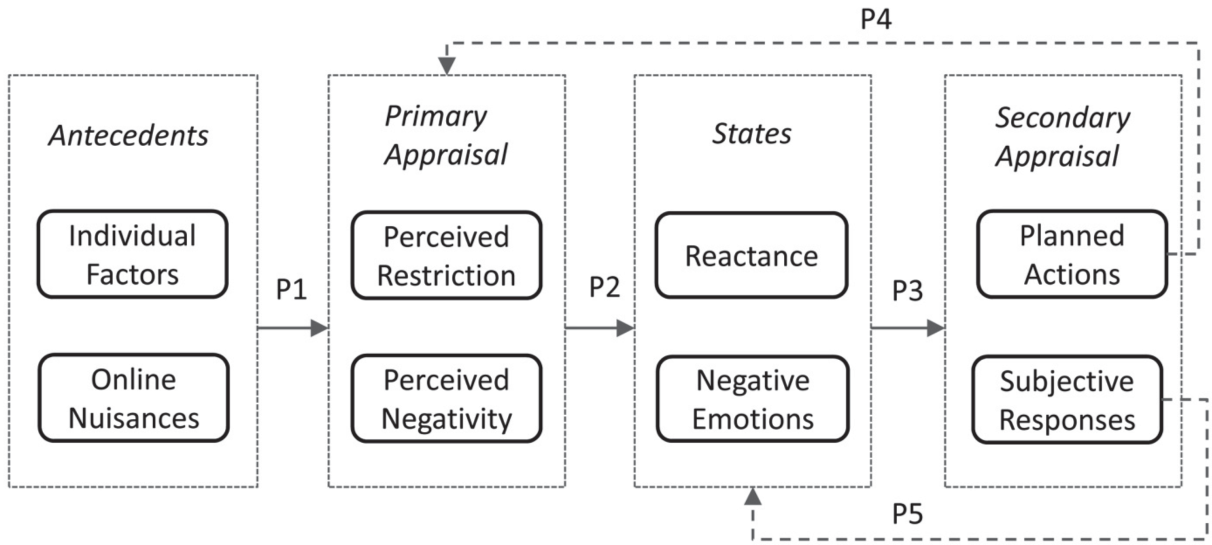

Figure 27: *The* Coping with Online Nuisance Encounters *(CONE) Model*

5.2 The Concepts and Propositions

5.2.1. Antecedents

Two types of antecedents exist during online nuisance encountering: individual factors and online nuisances. Individual factors or characteristics can include an individual's goals, expectations, beliefs, personality, and abilities. Online nuisances are characterized by designed features. These are attributes and properties that designers chose to either include or exclude as part of their design decision-making. Examples of nuisance design features can be those found in our studies in the form and behavior dimensions (see Table 5), as well as a main message for content when appropriate (such as in the case of online advertisements).

5.2.2. Primary Appraisal

During primary appraisal, individuals appraise whether the encounter with a nuisance object is a restriction on their control, yielding perceived restriction. Perceived negativity is the user's evaluation of the online nuisance to be negative, thus unpleasant or undesirable. Perceived restriction and perceived negativity are two different concepts, although they may be correlated. Perceived restriction focuses on an estimate of loss of control. Perceived negativity, on the other hand, focuses on whether the encounter with the nuisance object is positive or negative. High perceived restriction may lead to high perceived negativity. However, there may be little perceived restriction but still high perceived negativity, or little perceived negativity but high perceived restriction. Primary appraisal, according to psychological stress coping theory, is predicated on an individual's personal desires that the environment must meet and the requirements placed upon the individual by the environment (French, Rodgers, & Cobb, 1974). This means that perceived restriction and perceived negativity are the results of individuals (with their own factors) evaluating the nuisance object. Thus we have the following proposition.

> *Proposition 1. In an online environment, an individual user's characteristics and the characteristics of the online nuisance will influence the individual's perceived restriction and perceived negativity of the online nuisance.*

5.2.3. Experience Emotional and Motivational States

Negative emotions are subjective feelings one has, such as: annoyance, irritation, aggravation, frustration, stress, or anger. Reactance is a motivational state wherein the individual wishes to reestablish lost or threatened freedoms (J. W. Brehm, 1966; J. W.

Brehm & Cole, 1966; S. S. Brehm & Brehm, 1981). Dowd, Milne, and Wise (1991) developed the "therapeutic reactance scale" (TRS) which asks whether individuals are "bothered" or "upset" by reactance-inducing circumstances, and whether they "resent" authority figures. Reactance thus can stem, in part, from negative emotions felt on the part of the user. In addition, experiencing reactance can also result in certain negative emotions, as pointed out by Brehm (1966). Thus reactance and negative emotions can be highly related. In fact, in the literature, sometimes reactance and negative emotions are treated as analogies. For example, Quick and Stephenson (2007) measured reactance by asking participants the extent to which they feel, "irritated, angry, annoyed, and aggravated." The Hong Psychological Reactance Scale (S. M. Hong, 1992; S. M. Hong & Faedda, 1996; S. M. Hong & Page, 1989; Shen & Dillard, 2005) measured reactance using statements like, "the thought of being dependent on others aggravates me," "it irritates me when someone points out things which are obvious to me," and "I become angry when my freedom of choice is restricted," (S. M. Hong & Faedda, 1996). In this study, we treat reactance and negative emotions as two separate concepts. Negative emotions emphasize on subjective feelings. Reactance emphasizes on the desire to revoke or reverse current situation.

Individuals experience both reactance and negative emotions due to the primary appraisal, where they differentiate between benign and potentially harmful environmental conditions. Such evaluations can be described in terms of "harm/loss," "threat," and "challenge" (Folkman, 1984; Lazarus, 1993a). In our empirical study, users frequently identified harms, losses, and threats. They were much less likely to see online nuisances as potentially uplifting challenges. Negative emotions were also common in our study, with many users expressing annoyance, irritation, aggravation, and anger. Finally, users in our study frequently indicated how losses of control impacted their online experiences. They volunteered their own motivational feelings about restoring control and expressed negative feelings toward those who limited it in the first place. Accordingly, we have a second proposition:

> *Proposition 2. Perceived restriction and perceived negativity of online nuisances will generate reactance and negative emotions.*

5.2.4. Secondary Appraisal

Planned actions are potential, actionable responses one can take to restore lost control and thus change the perceived restrictions or rectify perceived negativity. Subjective responses are one's adjustment of attitudes or beliefs in order to deal with the negative emotions and reactance. The psychological stress coping literature refers to planned actions as problem-focused coping strategies and subjective responses as emotion-focused coping strategies (Folkman & Lazarus, 1985). Both stress and reactance theories address emotional-focused strategies, although the reactance theory does not explore subjective responses as thoroughly as psychological stress theory: several of the key emotional coping strategies found in the ways of coping checklist are not mentioned by Brehm (1966; S. S. Brehm & Brehm, 1981), including self-blame (e.g. blaming oneself for being unable to keep a lost freedom), tension reduction, or self-isolation (Folkman & Lazarus, 1985).

The reactance theory considers planned actions and subjective responses as reactance effects. This means that reactance will trigger planned actions and subjective responses. Combining the above discussions based on both theories, during secondary appraisal individuals act upon their negative emotions and reactance to evaluate and select from planned actions and subjective responses.

In our empirical study, we saw several planned actions, including: closing pop-ups and interstitials, muting audio, stopping video playback, complaining to advertisers, blocking other users (social media), and leaving the website. We also saw subjective responses: thinking more about the benefits of a system instead of its nuisances (emphasizing the positive), contemplating future improvements to systems (wishful thinking), and simply ignoring nuisances (distancing). In many cases, people adopted a mix of approaches to mitigate their negative emotions, act upon the reactance-based motivation to restore lost control, and improve the negative individual-to-environment relationship caused by the nuisance. Thus our empirical data reflects our understanding of online nuisance coping as described in the literature. We present a third proposition:

> *Proposition 3. A person experiencing reactance and negative emotions induced by online nuisance will adopt either problem-focused planned actions toward online nuisances, or emotion-focused subjective responses directed toward modifying their own psychological states (negative emotions and reactance), or both problem-focused actions and emotion-focused responses.*

5.2.5. Coping Result

Two additional processes that are implied in Figure 1 are about the coping result after executing either planned actions or subjective responses or both. If a planned action is taken, the perceived restriction and perceived negativity may improve (P4), which can further influence the newly found negative emotions and reactance. If a subjective response is enacted, the individual may experience different (possibly reduced) negative emotions and reactance (P5), even if the nuisance itself still exists. In either of these cases, if the nuisance having been addressed successful, no further coping may be necessary. In some cases, if these approaches are less successful, further coping may be required and the main processes in CONE will repeat. We present the fourth and fifth propositions:

Proposition 4. A person who addresses an online nuisance with planned actions may have changed the perceived restrictions and/or perceived negativity.

Proposition 5. A person who addresses an online nuisance with subjective responses may have changed reactance and negative emotions.

6. Discussion

In this section, we briefly summarize the limitations, scholarly implications, and practical implications of our exploration of the online nuisance landscape and the CONE model.

6.1 Limitations

There are several limitations in this study. Foremost, we acknowledge that this work is a beginning, not an end. We theorized from literature and from our empirical studies, but do not provide empirical validation of the CONE model and its propositions. Second, we acknowledge that the CONE model is not yet detailed enough to be a predictive tool. We developed it to identify and visualize the main concepts and processes that interplay during a nuisance encounter. However, we expect that the CONE model can eventually become a valuable tool to specify specific relationships and predict the effects of different design decisions on the user experience. Finally, we acknowledge several limitations in the exploratory empirical data collection. The survey emphasized just one context, online advertising. The focus group study emphasized two others, social media and mandatory organizational systems. These are not representative of the entire online environment, and future work in other contexts will undoubtedly reveal new insights about the nature of online nuisance encounters. Our coding approach to the data set was exploratory, emphasizing interesting insights and patterns. As our understanding of the online nuisance phenomenon matures, employing more robust analysis mechanisms is desirable.

6.2 Scholarly Implications

This work has two goals: 1) to understand what are considered nuisances by online users, and 2) to understand how online users react – behaviorally, cognitively, and emotionally – to these nuisances when they are encountered. In previous studies, online nuisances have been treated individually and as discrete objects. In this work, we adopt a new approach, exploring online nuisances in terms of a landscape. As individuals navigate the online environment, they encounter hosts of nuisances. Our work shows, in a relatively systematic fashion, what people consider as nuisances and why they are considered nuisances. Along the way, we provide a structured framework of content-form-behavior to differentiate nuisance characteristics.

Ultimately, our work synthesizes and expands the existing online nuisance literature. We suggest an important interplay between characteristics of the user and characteristics of nuisances. That is, the same nuisances may not be annoying to all users, and they may not be annoying to different users in the same way. While form-based nuisances seem to be largely an outcome of design decisions, content nuisances are often an outcome of the users' own subjective goals and expectations. Annoyances caused by the nuisance object's own behaviors seem to be the outcome of a contrast between design decisions and a user's individual characteristics. All of these conceptualizations suggest future directions for exploring the online nuisance landscape holistically rather than in a piecemeal fashion.

In addition, we posit the CONE model, drawing upon and combining two psychological theories. This model can depict and explain how individual users encounter, appraise, and cope with online nuisances, adding to the literature our theoretical understanding of negative emotion coping in the online environment. The CONE model also connects to our conceptualization of the online nuisance landscape, showing how antecedent factors play an integral role in individuals' appraisal of online encounters as either a nuisance or not. Again, the CONE model points the way toward future work in the study of online nuisances and is a framework for starting such examinations. Our work also demonstrates the long lasting value of these two psychological theories and how they can apply to relatively new segments of the online environment.

There are several exciting future directions for this work. We expect that reexamining existing studies in light of the CONE model will shed new light on the nature of various online nuisances, showing deeper connections between the online phenomenon that formerly seemed only loosely related. In addition, we are interested in empirically validating the CONE model and expand the application of the CONE model to broader online contexts.

6.3 Practical Implications

Those who conceptualize and implement web experiences for others are often confronted with conflicting design goals: they must design useful, usable and enjoyable online interactions for users while simultaneously capturing user attention and interest and meeting the objectives of various third parties. Designers have technical tools and capabilities at their disposal to do this, but do not always have the requisite knowledge to understand whether users will respond positively or negatively to certain design decisions. Our examination of online nuisances and the CONE model are a start to help them understand users' potential reactions and why these reactions from the users.

In particular, designers should understand how restrictions on control are a critical aspect for users when they appraise online nuisance encounters. Denying control to the user or taking it away once given is extremely frustrating and risks undesirable effects including annoyance, hostility, and even brand rejection or boycotting. When users do lose control, they may seek to reassert it through problem-focused coping. Designers should consider ways to make this reassertion straightforward and simple, even when it is tempting to attract attention for a few extra seconds by complicating the tools that will allow users to do this.

The advertising context is a particularly nuisance rich online environment, and advertisers should consider new techniques for attracting the attention of users while avoiding the most common forms of nuisance. A number of participants in Study 2 suggested their preferences in this regard, shown in Table 13.

User Preferences for Online Advertising
"I was more likely to pay attention because it was un-intrusive - my first instinct was not to get rid of it"
"If it's something relevant to a page I'm already on I am a lot more likely to check it out on my own."
"It's still an ad, but at least it provided a service."
"I like ads like this one that seem to respect me."
"This is a good ad because they are not forcing it down your throat."
"The was really attractive so it got my attention."
"It was helpful in some way."
"I am fully aware that these ads can be incredibly valuable to companies, the key is to try not to alienate your users in the meantime."
"I'd love it if the advertisers would realize the truth of the old saying: 'Less is more.'"
"Some ads can be useful, sometime I pay more attention to small text adds than huge animated, blinking adds."

Table 7.13. User preferences for online advertising

From these comments, web users seem receptive to the notion that web advertisements don't necessarily have to be nuisances despite their currently poor reputation. Furthermore, capturing a user's attention in a positive manner is not necessarily a function of brighter color, faster flashing, louder sounds, sexualized content, deceptions, or interruptions. Users may be far more receptive to tastefully presented information that will benefit them or experiences that enrich their lives through beauty, humor, storytelling, or in other ways. It should also be noted, however, that users may or may not be in earnest when they suggest that subtle or tasteful ad content is a superior vehicle for attracting their attention; it is easy to suggest this when one is annoyed and wishes to see things change.

7. Conclusion

The online environment can be an exciting, engaging, interesting, and useful place, but too often individuals perceive it as distracting, frustrating, and annoying. In some cases, deliberate design decisions mar the user experience. In others, seemingly benign design choices clash with user goals, expectations, and other characteristics.

Though the exact content, form, and behavior of online nuisances can vary widely, individuals seem to appraise and cope with them through a single process, which we capture in the CONE model. The CONE model expresses how nuisances are appraised and how individuals cope with the resulting negative psychological states. The nuisance landscape and the CONE model together provide guidance to designers on how they might avoid creating nuisances in the first place or make nuisances easy to cope with and move on from if they do happen to occur.

Nuisances and the users who encounter them are highly complex, and there is no magic bullet for making the online environment a utopia free of all distractions, frustrations, and annoyances. However, our increased understanding of this complex landscape and the coping processes are an important start toward reaching a new potential for online user experiences.

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CHAPTER 8: Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO)

Prestopnik, N. & Foley, A. (2012). Visualizing the Past: The Design of a Temporally Enabled Map for Presentation. *International Journal of Designs for Learning*. (3)1, pp. 52-60. [1]

Abstract

We present a design case for a prototype visualization tool called the Temporally Enabled Map for Presentation (TEMPO). Designed for use in the lecture classroom, TEMPO is an interactive animated map that addressed a common problem in military history: the shortcomings of traditional static (non-interactive, non-animated) maps. Static maps show spatial elements well, but cannot do more than approximate temporal events using multiple views, movement arrows, and the like. TEMPO provides a more complete view of past historical events by showing them from start to finish. In our design case we describe our development process, which included consultation with military history domain experts, classroom observations, application of techniques derived from visualization and Human-Computer Interaction (HCI) literature and theory. Our design case shows how the design of an educational tool can motivate scholarly evaluation, and we describe how some theories were first embraced and then rejected as design circumstances required. Finally, we explore a future direction for TEMPO, tools to support creative interactions with visualizations where students or instructors can learn by visualizing historical events for themselves.

1. Introduction: A Design Challenge

Maps purport to visualize many things in the military history context: movement on a battlefield or in a theater of war, the impact of combat on unit cohesion and readiness, and the role of luck, timing, and decision-making in battle. These elements of military-historical study are not just spatial in nature. They are spatiotemporal. They require the visualization of time as well as space.

Most military-historical maps do a poor job of this kind of visualization. This is because most maps in military history, especially those found in books or used in the classroom, are static: they are printed on paper or digitally represented as images in static media such as PowerPoint. No matter how beautifully rendered or organized, static maps show only snapshots of individual moments, never the true temporal flow of a military-historical event. Arrows, unit and position marks, and multiple views are able to represent only a shadow of what really happened during past moments of great consequence.

Yet maps continue to have value for the student of military history. Maps abstract and simplify our understanding of terrain. Maps also clarify the physical battle space, with many techniques developed over the years to visualize terrain features, by either abstracting or emphasizing various details (Imhof, 1965, 1975; Kraak et al., 1997; Muehrcke, 1990).

In this paper, we describe the design and development of a spatiotemporal visualization tool for military history, the *Temporally Enabled Map for Presentation* (TEMPO). We designed TEMPO to address the problem of static maps in military history, specifically to seek ways that an interactive, map-like tool could enrich learners' perceptions of the past: their understanding of abstract but important concepts such as luck, timing, and the nature of decision-making in war, as well as their understanding of terrain and the battle space. As a prototype, TEMPO addresses just one military-historical event (the Battle of Midway, 1942) but demonstrates the potential for temporally-enabled maps to address many different kinds of past events.

As an overarching goal of this project, we used TEMPO as a vehicle to explore the dynamics of embedding interactive visualization technologies into the military-history education context. In the following design case, we describe how our design decisions were impacted by a central research question: how do interactive visualization tools impact the instructor and student experience in military history education? We state this question not because we intend to answer it fully here, but because it underpinned the entire TEMPO project, from conceptualization through design to implementation and evaluation.

The pairing of scholarly inquiry and design activity is known as *design science* (Hevner et al., 2004; March & Smith, 1995; Simon, 1996; Zimmerman et al., 2007), and we adopted this approach for the TEMPO project. Design science projects, which include a host of activities, including theorization, design, and detailed evaluation (Prestopnik, 2010), tend to have too large a scope to compellingly report in just one paper. Accordingly, we concentrate here primarily on our design decisions and activities. Our scholarly findings on student and instructor experiences with TEMPO have been presented elsewhere (Prestopnik & Foley, 2011), and are of continuing interest.

In this paper, we explore TEMPO as a *design case*, adopting Boling's (2010) and Smith's (2010) perspective on this reporting methodology. According to Boling (2010) a design case is, "a description of a real artifact or experience that has been intentionally designed." We present a detailed description of TEMPO and the many decisions – some supported by our prior design experience, others supported by research activity – that led to its successful implementation and evaluation.

2. Background

We (the authors) are both researchers at Syracuse University, and we both have backgrounds as interactive designers. In addition, one of us (Nathan Prestopnik) also has a background in military history, holding an undergraduate degree in the subject. Recognition of the problem with static maps in military history was therefore an extension of our prior experiences, and we started the TEMPO project of our own volition for the sake of exploring this interesting and multi-faceted challenge. Our goal for TEMPO was to address an interesting and relatively unexplored design problem by building a system or tool. We also conducted HCI, visualization, and education research around the system that we ultimately built. The TEMPO project was small and rapidly executed, with just two researchers participating and a timeline of just one semester to conceptualize, design, implement, and preliminarily evaluate.

3. Subject Selection

Our design process for TEMPO began with a careful search for an appropriate military-historical subject to visualize. We eventually settled on the 1942 Battle of Midway, but considered other battles, including Gettysburg in 1863, Stonewall Jackson's spring 1862 campaign through the Shenandoah Valley, the Roman defeat in the Teutoburg Forest in 9 AD, and Nelson's victory at Trafalgar in 1805.

For practical reasons, we initially felt it was important to choose a relatively one-dimensional battle, featuring only ground or naval combat, avoiding the complexities of visualizing a multidimensional land, sea, and air campaign. We also recognized that it would be important to select a well-documented battle in order to make our visualization as accurate as possible. More importantly, we sought a conflict where luck and timing, often critical elements of conflict, had been important to the outcome. Our hope was that TEMPO could help dispel the false "Hollywood" view that historical battles are decided by heroic generals enacting brilliant feats of strategic and tactical legerdemain. Beach (1986) suggests a more realistic perspective in his discussion of the battle between the ironclads *Monitor* and *Virginia* during the American Civil War: "The professionals in both navies addressed themselves to what had gone right and what had gone wrong in the epic battle…. It was quickly apparent that the decision might have gone either way and that many incidental occurrences had had totally disproportionate effects," (Beach, 1986, p. 299)

To help select a historical moment to visualize, we engaged in an interview and discussion with a domain expert, a senior military history instructor at Syracuse University. Our domain expert suggested that the Battle of Midway might answer our needs better than some older battles. Even though Midway included both naval and aerial combat, the battle space was simple (open ocean with just two small islands of any consequence), and the battle itself featured several key moments of luck and timing that had a direct impact on its outcome. In addition, the main events at Midway were well documented and occurred over a time span of 15 hours, which seemed a substantial but still feasible amount of time to work with. Finally, Midway was an important and consequential battle, the visualization of which would be useful and interesting to a wide audience, including history educators, students, military professionals, political decision makers, and the general public. After reviewing several sources suggested by our domain expert (see Prange et al., 1982; Spector, 1985), we concluded that Midway would be an ideal engagement for us to visualize.

4. Context of Use

Static maps are used in virtually all areas of the military history domain, from museums to libraries to books to classrooms. Their ubiquity required us to narrow our interest; developing TEMPO for use in museums, libraries, or other venues would have been both possible and interesting, but we chose a more typical educational context: the classroom lecture. We were especially interested in lectures because in military history education these are a context where the use of advanced technologies is still relatively limited. Findings from our research question on the student and instructor experience could have potentially great impact.

Our domain expert invited us to attend an undergraduate lecture he was presenting specifically on the topic of Midway (as well as the larger Pacific theater of World War II). We attended, observed, and made detailed, ethnographic style notes (see Emerson et al., 1995) on the classroom space, the style and delivery of the instructor, the students, and the lecture itself. This exercise was very helpful, allowing us to gain a sense of how TEMPO might fit into existing lectures and work within the typical lecture space – large auditorium classrooms with digital projection screens and control consoles for the instructor.

We noted with interest that our domain expert used very few slides. He lectured for two hours from memory in a highly narrative approach, almost like storytelling, only occasionally quoting from news clippings or books. Projected media in his class were limited to photographic images of historical figures and a variety of different maps. Most of the maps only approximated what he was trying to demonstrate to the class, and he would frequently have to clarify details that were obscured, missing, or invisible to the students in the class. For example, one map of the Midway battlefield was too large, encompassing most of the Pacific Ocean. Our domain expert directed the class's attention to Midway Island itself with the accompanying apology, "well you can't see this very well, but Midway is down here..." Units and events from the battle were approximated with hand gestures and explanations.

During a later evaluative interview, our domain expert talked about the lecture as a pedagogical tool, saying that while many consider the lecture to be a, "dead and destructive form of pedagogy," he views it as an, "art form… a chemistry between lecturer and student." Despite his relative lack of media use during the lecture, our domain expert's presentation style made the talk itself fascinating, with most students paying careful attention and remaining involved despite the ubiquity of Facebook and YouTube applications on laptop screens prior to the start of class. Based upon our observations, we developed a key goal to develop TEMPO as a minimalist tool that could accompany and augment a well-delivered lecture, rather than replace it.

5. Tools and Technology

Because TEMPO was to be a prototype system, we oriented our design process around speedy development and rapid iteration. We used Adobe Photoshop to produce visual layouts for several different design drafts which were evaluated in discussions between the authors and by presenting them to various potential users (colleagues, students, etc.) for feedback. Though informal, this process suggested many changes and improvements to the design of TEMPO.

Once we had a settled on a final design (see below), the visual mockups were rebuilt using Adobe Flash as our development framework. If we were to develop a commercial version of TEMPO, Flash would not be our first platform choice because it limits the use of certain technologies (particularly 3D virtual environments). Nonetheless, Flash is an excellent development environment for rapid prototyping because it is flexible, easy to work with, and finished Flash files (.swf files) can be easily embedded into web pages and played on most computing devices. An important limitation created by this choice is that .swf cannot be played on iOS mobile operating systems. Our decision to use Flash was motivated by the standard lecture technology found in most classrooms (i.e. usually not mobile technology) as well as our deep knowledge of Flash compared to newer platforms that we were less familiar with. As the project evolved, however, the application of TEMPO (potentially) outgrew its envisioned but limited classroom use. Switching to a technology with better cross-platform support such as HTML5 would no doubt be preferable for future work on TEMPO.

6. The Finished Artifact

We produced several versions of TEMPO before settling on the final design of the prototype (though in acknowledging the iterative nature of design science, we understand there are still many future possible improvements to TEMPO). We describe several of false starts and dead ends later in the paper, many of which were highly interesting and helpful to our design process. In this section we describe the finished artifact and the thinking that led to it. A working version of the finished TEMPO artifact is embedded in this document.

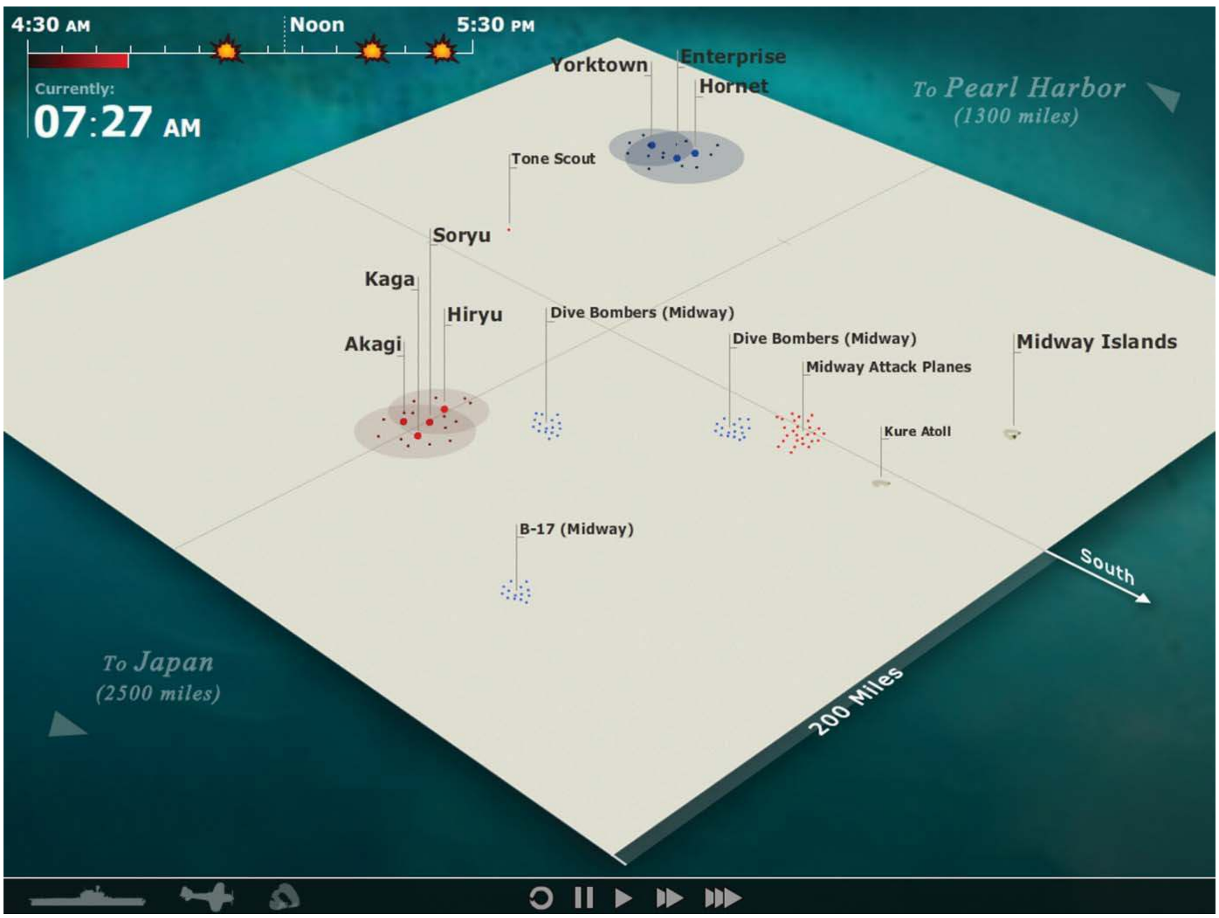

Figure 8.1. The final TEMPO interface.

The finished TEMPO visualization tool shows an animated overview of the Battle of Midway. Japanese forces appear in red and US forces appear in blue. Ship and aircraft icons in TEMPO were abstracted to single points for clarity and perceptibility due to the scale of the battle, which takes place over some 160,000 square miles.

Units are labeled clearly by ship name or aircraft type, as are the two islands involved in the battle (Midway and Kure Atoll). Photographic imagery of ships, aircraft, and location are readily available by clicking on their labels, allowing TEMPO to show both the time-based data of events as they unfold, plus more qualitative types of information ("how it was"). This feature was inspired by our domain expert, who indicated that helping students understand how the past looked and felt is an important aspect of his talks. Labels can be toggled on or off using controls at the bottom left of the TEMPO screen, a feature included to reduce visual clutter if desired by the lecturer. TEMPO generally follows the well-known visualization guideline of "overview, filter, and detail" (Shneiderman, 1996).

7. Visualizing Time and Space

TEMPO can be played at three speeds (including real-time), paused, and restarted at will. The temporal element redresses the problem of non-interactive maps, enabling the tool to visually convey the tempo of battle and illustrate abstract concepts that paper maps cannot, notably the elements of luck, timing, and friction that occur on the battlefield. We drew upon DiBiase, MacEachren, Krygier, and Reeves (1992), who describe three key variables in visualization animations: *duration* (the frame rate of an animation, or how long individual frames remain visible before the next frame is shown), *rate of change* (the magnitude of change which occurs between frames), and *order* (the sequencing of events within an animation). Manipulation of these three variables suggests three possibilities for a temporally enabled map: maps that "emphasize the existence of a phenomenon at a particular location," maps that, "emphasize an attribute of the phenomenon," and maps that, "represent change in a phenomenon's position or attributes," (DiBiase et al., 1992). Each of these types affords various forms of information. TEMPO most emphasizes the existence of a phenomenon (combat) at a particular location (various locales on the Midway battlefield).

We also drew upon Kraak, Edsall, and MacEachren (1997), who describe two additional aspects of animated maps: *display time* (the timing of events as they unfold for the viewer of a map) and *world time* (the real time which passed as events unfolded). Display and world time may be equal (i.e. a "real time" map), but need not be. There are situations where a real time display of geographical data would not be useful, for example, a real time map of the Battle of the Somme, which took place over 4 ½ months (Marshall, 1964). However, showing portions of a battle in real time to emphasize the actual speed at which events occurred and the nature of naval aerial warfare, which includes long periods of inactivity followed by intense periods of combat, could be extremely effective. We included a real-time play speed in TEMPO with this specific use case in mind.

8. Design Iterations

8.1. Placement of Controls

Our study of the lecture context led directly to the visual representation and placement of many TEMPO elements. For example, the play controls, in an early version of the design, were placed centrally in the screen. TEMPO was designed to have an expert lecturer in control at all times, and we realized that the play buttons could and should be made more unobtrusive so they wouldn't distract students from the main content of the visualization. Accordingly, we reduced the play controls in size and moved them to the bottom edge of the interface.

The timeline in the upper left also underwent changes as the classroom/lecture context became more familiar to us. In the same early version of TEMPO, the timeline extended across the entire screen and contained great detail, with several dozen key moments identified by time. After viewing this design projected in a classroom, we felt the timeline was too detailed to be easily viewed, and too restrictive to the lecturer, who might not weight the moments visualized with the same importance as we did. The timeline was changed to show only the most critical elements of battle, and to make it clear when aircraft carriers – generally understood by historians to be the most critical units of the battle – were destroyed.

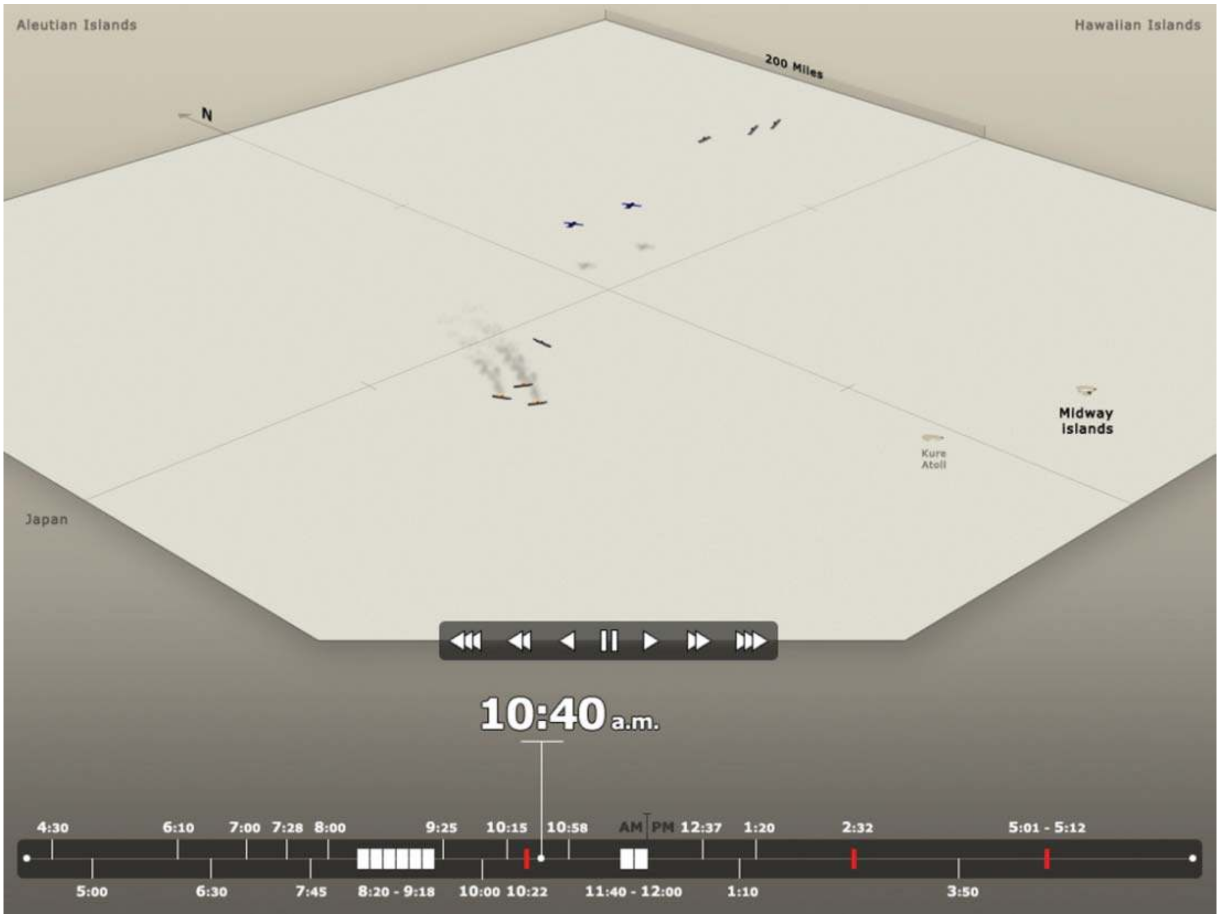

Figure 8.2. The first design iteration: an early version of the TEMPO interface.

8.2. Color and Imagery

Colors and icons were changed from early versions of TEMPO. Icons were simplified from tiny ship and airplane images (see Figure 2) to abstract colored dots. The ship and aircraft icons in early versions were far out of scale, making the battle appear much smaller geographically than it really was. At the same time, these icons were still too small to be perceived easily for what they were. In addition, because all were the same color, it was difficult to differentiate American from Japanese forces or make much sense of the battlefield events, particularly when projected and viewed from the back of a classroom. Simple colored dots overlaid on a neutral field (we did include some blue color in the margins of the final design to provide an impression of ocean water) addressed both issues. Our design process validated the basic notion that, "It is abstraction, not realism, that gives maps their power," (Muehrcke, 1990).

Tufte (1990, 1997, 2001) suggests visual simplicity in his discussion of 1 + 1 = 3 effects and chartjunk, where overlaid or unnecessary elements interact with each other to produce visual effects that seem to be more than the sum of their constituent parts. This effect is sometimes positive, as when visual elements, labels, and motion combine to tell a more compelling story than any individual layer could alone. The 1 + 1 = 3 effect can also be negative, as when overlaid elements with too much visual weight result in clutter and confusion instead of clarity. The use of bright, contrasting colors to draw attention is also well noted in the design, visualization, and cartographic literature (Imhof, 1965). For TEMPO, we applied this design advice in myriad ways, seeking a balance between content detail and interface simplicity.

9. TEMPO and the Rejection of Theory

We have previously described a number of visualization theories that helped to inform the design of TEMPO. It was also our intention to draw heavily upon time geography theory (Hägerstrand, 1970, 1975, 1982; Miller, 2005; Raubal et al., 2004; Thrift, 1977), a way of examining events which occur in both space and time. We initially felt that a stronger theoretical grounding and a unique departure from basic animation would benefit TEMPO and its end users.

Time geography, according to Thrift (1977), is “a respect for the conditions which space, time and the environment impose on what the individual can do.” Individuals and social systems will be constrained by time and physical space: mutually dependent resources which may be spent but which are limited within any given context (Thrift, 1977). There are three basic dictates of time geography that describe these limitations (Hägerstrand, 1970; Miller, 2005): 1) capability (the ability of an individual to trade time for space for movement), 2) coupling (the need for individuals to meet at specific times and locations in order to accomplish tasks), and 3) authority (the ability for authorities to limit physical access to certain places at certain times).

Though time geography theory was conceptualized with civil society in mind, calculations of space vs. time, capability, coupling, and authority also seem highly applicable to representations of military historical events. The battle of Midway, for example, took place over vast distances, and the destruction of the Japanese carrier fleet on June 4, 1942 happened because of a remarkably fortunate (from the American perspective) confluence of events as planes and ships came together in time at space at exactly the right moment for victory to be achieved. Of course, the battle was also about authority, as American and Japanese forces sought to deny Midway Island to their opponent while claiming it for themselves.

We conceptualized an early version of TEMPO which drew heavily upon time geography theory, especially in adopting Hägerstrand’s (1970, 1975, 1982) notion of the space-time prism, a visualization technique for showing connections in time and space using intersecting lines in a 3D space. In a space-time prism, lines represent individual people (or ships, aircraft, and other units in our Midway context). Interconnections between lines represent moments where these individuals cohabit the same geographical spaces (e.g. the same room, building, street, island, etc.). Sloped line segments represent the time it takes to move in physical space; lines can never merge perfectly horizontally, since that would imply a travel time of zero. Slope serves as an indication of how long it takes individuals to traverse physical space in order to reach a given destination.

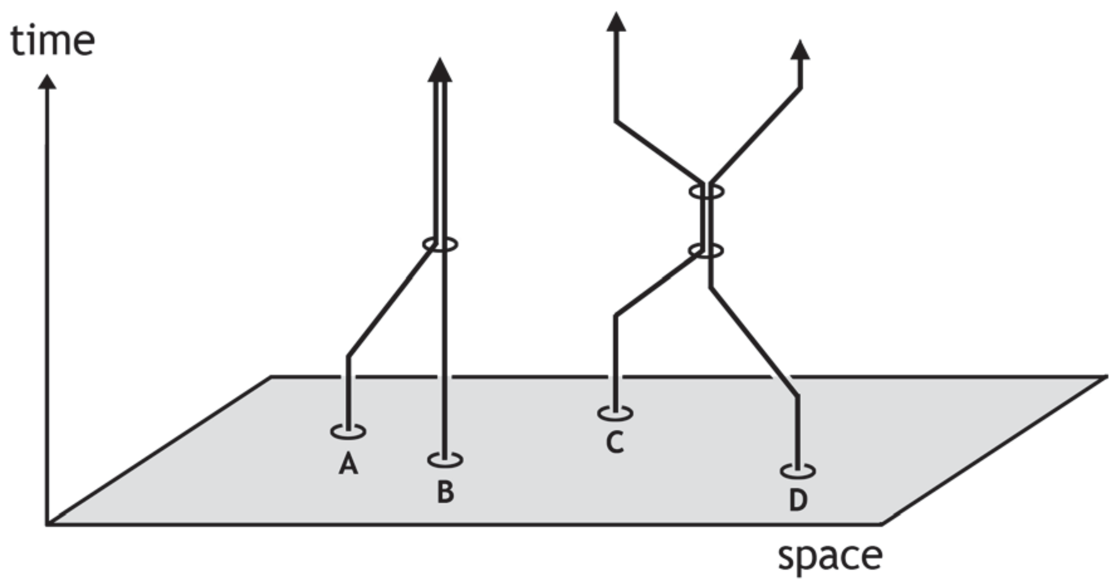

Figure 8.3. The space-time prism. In the 3D space shown, three individuals interact across space and time, coming into geographical contact with each other at various points, remaining in contact for defineable periods of time, and then parting ways.

Our intention was to embed the TEMPO animated map into a space-time prism. We planned to place the map and animated unit movements on the “floor” of the prism, and allow the intersecting lines to move vertically downward as time unfolded, showing how different units would move and eventually intersect in physical space. This suggested itself as a unique way to emphasize and visualize elements of luck and timing in the battle. The lines of intersection would draw student attention to key moments of the battle (e.g. the ultimately successful American attack on the Japanese carriers) when many of them converged simultaneously.

Over the course of developing TEMPO, we realized that an important aspect of design science is to question theory under specific circumstances of design and use. The TEMPO design process gave us a powerful opportunity to apply theory to a real design situation and to question its value to our specific use context. While the space-time prism visualization technique initially seemed highly suitable for TEMPO, we eventually dropped our interest in it. An early design for TEMPO which favored the space-time prism technique was confusing to potential users and required too much explanation to make sense of; this version had turned TEMPO into a tool for teaching time geography theory, rather than for teaching military history. Furthermore, it soon became apparent that a successful implementation of this technique would require a more advanced development platform than Adobe Flash. A 3D implementation of TEMPO would be more likely to make successful use of time geography theory. We ultimately excised time geography theory and space-time prisms from the repertoire of visualization techniques that we deployed in TEMPO. However, the theory remained valuable to us as a framework for thinking about the various events that occurred during the battle of Midway.

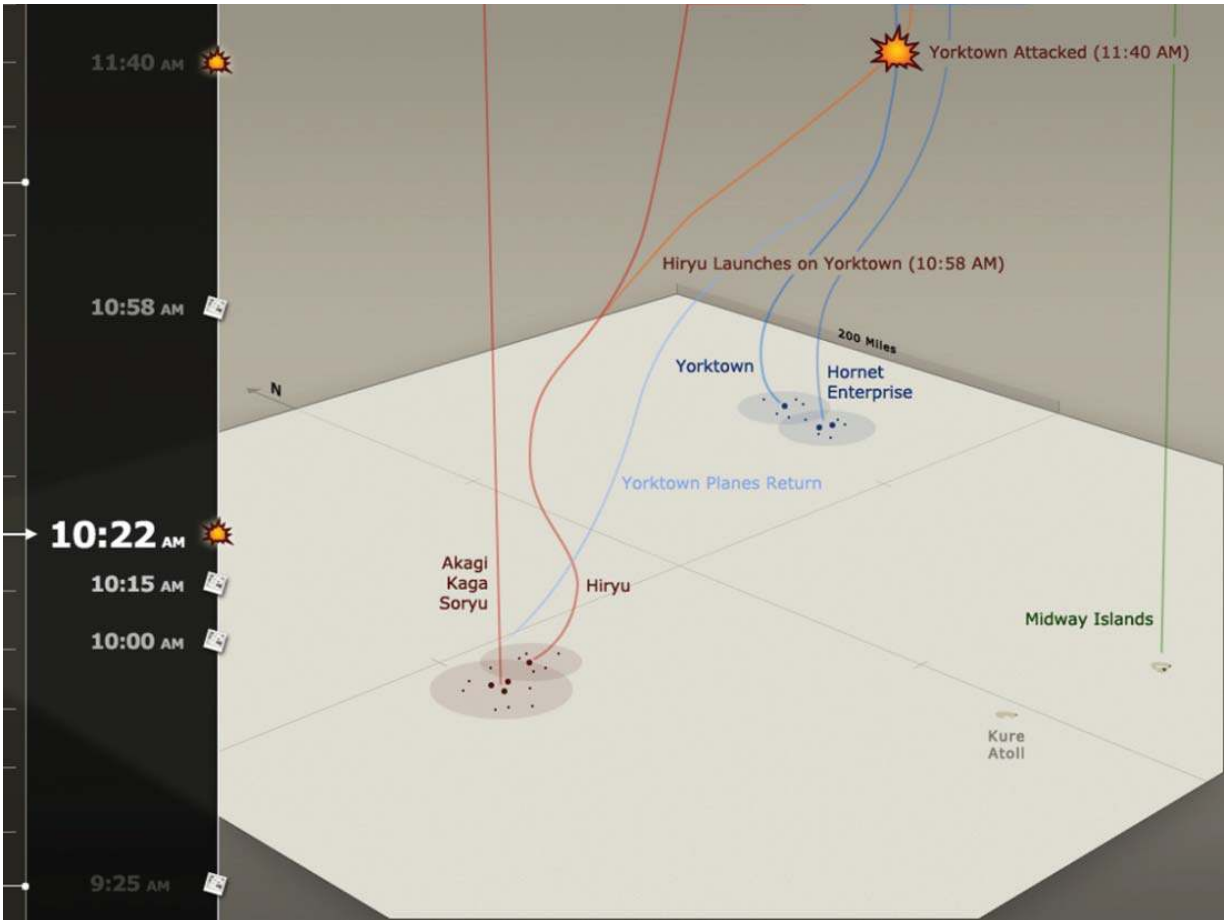

Figure 8.4. Early version of TEMPO, incorporating time geography theory and space-time prisms. We ultimately rejected this version for being too confusing and requiring too much background knowledge of the theories upon which it was built.

Despite our rejection of the time-geography version of TEMPO, however, it is worth noting that a variety of positive improvements were developed in our time-geography motivated design. We began working on repositioning the timeline, using a left-oriented "waterfall" view with fewer events and larger text. We eventually transformed this into the even simpler timeline found in the final TEMPO instantiation. We also developed the simpler red and blue dot system for identifying units in this version of TEMPO, though we had not yet settled on a unit labeling convention.

10. Visualizing the Past: Challenges and Opportunities

Even though Midway is a well-documented and extensively written-about battle, there was no readily-accessible database of ship and aircraft positions to work with when creating TEMPO. Rather, we had to build our animation by hand, drawing upon paper history books and static maps as resources. We embedded a detailed map of the battle of Midway into the TEMPO application, positioning, sizing, and distorting it to fit our perspective view. Using published material on Midway and our embedded map as a guide, we began to establish animation key frames (stored in a dynamically parsed text file) so that each ship and flight of aircraft would accurately follow its correct path of travel in the correct amount of time while also displaying important events.

Ship by ship, plane by plane, we built the battle up over many days of flipping through history books, consulting published battle logs, and examining the static maps we had at our disposal for key event times: the time that Japanese aircraft were launched toward Midway, the time of the Midway attack itself, attack times for each separate US aircraft flight, individual times for each carrier that was destroyed, etc. No single book or resource contained every one of these pieces of information, and no resource organized them in a fashion that was ideal for our visualization project. Most resources that we used presented the battle of Midway as a story; important technical and time details were intermingled with a variety of other kinds of information across hundreds of pages of text and on dozens of maps. Finding, deciphering, connecting, and visualizing this material was a tremendously difficult, labor intensive, complex process. Despite this – or rather, because of it – our design activities ultimately suggested an interesting new research question: what do people gain by visualizing information for themselves?

11. Creative Interactions with Visualizations

Visualizations are frequently claimed to have cognitive or learning benefits for students in various fields, but results from studies empirically attempting to establish this connection are mixed (e.g. Geelan & Mukherjee, 2011; Lowe, 2004; Piburn et al., 2005; Winn, 1982). Visualizations have also been explored as a means of engaging students (e.g. Grissom et al., 2003; Naps et al., 2003; Naps et al., 2002; Schweitzer & Brown, 2007), with similarly mixed results. Visualizations appear not to be adopted into the learning experience often enough or deeply enough to have the expected impact on student engagement or learning.

Our own experience was that the process of visualizing the Battle of Midway for ourselves made us vastly more knowledgeable than when we began, not just on the comparatively small amount of detail that went into the TEMPO visualization itself, but on the larger scope, meaning, and context of the battle. TEMPO shows just one day of the battle (the main and most eventful day), but there were related naval actions resulting in destroyed ships and killed men on the days preceding and following the sinking of the *Akagi*, *Kaga*, *Soryu*, *Hiryu*, and *Yorktown*. Understanding the entire course of the battle, including these other events and their larger tactical and strategic purpose, was necessary in order for us to meaningfully visualize what happened on June 4, 1942. We learned more about World War II history from the act of developing TEMPO than we ever would have from its use alone.

We also noted during our design activities that visualization scholars tend to focus on *representation* (techniques for visualizing specific kinds of data) rather than *interaction* (the ways that people interact with and use visualizations) (Chen & Czerwinski, 2000; Ellis & Dix, 2006; Thomas & Cook, 2005; Tory & Möller, 2004; Yi et al., 2007). In particular, there is virtually no literature on how the act of building visualizations can impact the person who creates them, nor much scholarly writing on the differences in this act of creation between quantitative and qualitative forms of data. Yet it seemed from our design experience that creating visualizations for oneself could have a potentially huge impact on learning and engagement with historical material.

From this we envision a next step for TEMPO called the *TEMPO Creator*. *TEMPO Creator* would be a tool with affordances (map and animation functions, unit creation and placement tools, annotation features, timelines, etc.) for instructors and students to develop their own visualizations of past historical events, military or otherwise. *TEMPO Creator* might also contain features to streamline the process of finding information and "pinning" it to the main map and timeline, easing the work of an instructor who wishes to prepare such visualizations for ready use in class (important affordances to include, since adding content to TEMPO was, at times, tedious). Advances in information retrieval and natural language processing make it theoretically possible to analyze some historical resources automatically, extracting relevant bits of information and prepping them for use in *TEMPO Creator*. At the same time, students may find more educational value in seeking such material manually during a classroom or homework exercise. The notion that history students could complete assignments in a format other than the written word is somewhat radical, but is well in line with arguments made by historians such as Moss (2004, 2008) and Staley (2003) that written historical material can be effectively augmented with visual material. As designers (and a former history student) ourselves, we are comfortable acknowledging the value of both written and non-written work in many different subjects. We think a tool like *TEMPO Creator* could add a great deal of value to historical study, without distracting too much from more traditional modes of learning and scholarship.

Following the design science tradition (Hevner et al., 2004; March & Smith, 1995; Simon, 1996; Zimmerman et al., 2007), we see an important future direction for our work with TEMPO: developing a prototype of *TEMPO Creator* with the intention of exploring its use in an educational context. The opportunities for scholarly study around a tool of this nature include 1) exploring ways that creating visualizations for oneself can impact learning and engagement, 2) exploring creative visualization interactions from a human-computer interaction standpoint, 3) exploring innovative uses of computer technology for parsing and understanding historical materials, and 4) exploring the interplay of quantitative and qualitative data in historical visualization.

12. Conclusion

We presented a design case for the *Temporally Enabled Map for Presentation* (TEMPO) a prototype visualization tool designed for use in the military history classroom. Coupling our design activities with theoretical and evaluative research efforts, we explored how visualization tools can impact the instructor and student experience, and how different visualization techniques can shape the design and use of a tool like TEMPO. Ultimately, our design efforts led us to an even more exciting possibility: a tool to allow students and instructors to learn as they create visualizations for themselves. This tool, called *TEMPO Creator*, is our next step in studying the confluence of design, military history, human-computer interaction, and visualization.

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CHAPTER 9: Discussion

Each of the previous three chapters showcased example papers written from design science projects (*Citizen Sort*, CONE, and TEMPO) organized around the TDE model. In this chapter, the example projects and the TDE model itself are analyzed in broader detail. Each section of this chapter focuses on key elements of the TDE model, including context, partnerships, theory, design, and evaluation. Additional implications for the overall model are also discussed, as are the research questions developed in chapter one.

1. Why Does Context Matter?

Context is the natural starting point for both design and research. For designers, a clearly established context can help to define design constraints – useful restrictions that help to guide creative acts toward meaningful outcomes (Lawson, 2005). HCI practitioners employ techniques like use case analyses, co-design sessions, interviews, observations, and field studies to understand context and, by extension, design constraints. Though the idea seems counterintuitive, constraints actually make design easier by imposing restrictions on what features are permissible in a finished IT artifact and what those features might look like. Constraints are the boundaries of a designer's canvas, and they stem from a thorough understanding of context.

Constraints and context are no less important for design scientists than for HCI practitioners. Design scientists must contend with the challenges of pairing scientific inquiry with design. Just as constraints limit design possibilities in meaningful and useful ways, so they can also help to focus a researcher's interests toward questions and problems that are interesting and impactful. Formative evaluation and literature review can both be highly valuable for establishing contextual boundaries. Furthermore, both scholarly and design constraints are usually outgrowths of a single context and tightly interrelated. Research questions can inform design decisions just as design limitations can illuminate meaningful areas for inquiry.

Understanding the constraints and contexts of a TDE design science project is more challenging than understanding the constraints of non-research projects. In commercial design, clients bring a host of constraints to the designer: business requirements and a user base, technical or artistic preferences, laws and regulations, and even mundane details like color schemes and logos. Design scientists typically start with none of this. The nature of scientific research is to explore unknowns and ask questions. Almost by definition, design scientists are working on problems where few, if any constraints have been previously established. In such environments, defining context is a critical early step that allows design and research to continue.

1.1. *Citizen Sort*: Ideation about Context using Research Questions

The *Citizen Sort* project, like many design science projects, began with broad guiding ideas, namely that citizen science could be studied as a form of socio-computational system. The first year of the project was spent transforming this area of general interest into a set of research questions and design requirements by defining a context and establishing constraints. Using an iterative approach and formative evaluations as a guide, more than 40 possible research questions about citizen science were developed for areas as diverse as mobile technologies, visualization, data collection and validation, design support tools, enabling citizen science participants to become independent scholars, and purposeful games for citizen science. Some research questions were broad and general, what Creswell (2009) would call “central research questions.” Others were detailed and highly specific, akin to testable propositions or hypotheses.

Each question probed an interesting scholarly issue within the broad citizen science/social computation context. In addition, each question had implications for possible design decisions. For example, the question, “What positive or negative effect(s) do games and game-like features in citizen science have on data quality and validity?” implied that the citizen science game(s) to be designed should include purposefully chosen features that could be correlated to data quality in various ways – the beginnings of a meaningful design constraint.

During formative interviews, many scientists involved in various extant citizen science projects had expressed an interest in games as a mechanism to recruit and retain participants (Prestopnik & Crowston, 2012a). This was also an interest of the researchers involved in the *Citizen* Sort project: at the conclusion of the one year period of question development, the research questions about purposeful game design seemed the most interesting and novel from a standpoint of HCI scholarship. Purposeful games soon became an integral contextual element, but narrowing the research interest from citizen science in general to purposeful citizen science games was only a start. There are many different kinds of games and many different kinds of citizen science projects, not all of which are equally interesting or useful to study. Literature on games and game design became a useful guide.

Scientists interested in using games to attract participants to their work often think about "gamification" – using badges, points, or scores to reward players for work. Game designers critique this perspective, noting that the player experience encompasses far more than simple rewards (Salen & Zimmerman, 2004; Schell, 2008). Many other things are important to a meaningful play experience: thematic elements, clever game mechanics, compelling stories, interesting characters, meaningful decisions, engaging challenges, and immersive game worlds (Malone & Lepper, 1987; Schell, 2008). Designing meaningful game experiences can be tremendously challenging. The costs – in terms of resources, time, expertise, and money – are usually high. Most successful citizen science games still continue to rely on points and leader boards to engage their players because these systems are simpler to conceptualize and develop.

The notion of meaningful game experiences in the context of citizen science raised highly interesting questions: could an interactive story motivate players to undertake scientific activities? What kind of players might such a story attract? What impact might interactive story games have on player engagement, performance, and data quality? A fortuitous pairing of design constraints and research questions emerged. *Citizen Sort* would compare elements of meaningful play – particularly interactive storytelling – to more traditional gamification approaches – points, badges, etc. – in the context of citizen science. Two web-based games, one story-driven and one points driven, would be developed, along with a portal website to help players register, play, and track their activities.

Most IS scholars adopt a conservative perspective on design that insists upon empirical support for design decisions. In game design this is not always possible. While good data and powerful theories exist to guide some kinds of decisions, the creation of compelling stories, relatable characters, and immersive game worlds is not fundamentally an empirical exercise. Rather, Lawson's (2004, 2005; Lawson & Dorst, 2009) view of designers as experts is more relevant. Accomplished game designers have created a vast heuristic understanding of how to create and tell interactive stories based upon prior precedent and their own experience.

1.2. CONE: Toward Context, with Theory and Evaluation as Guides

The coping with online nuisance encounter (CONE) model evolved out of an interest in how much tolerance different people have for various kinds of online nuisances – pop-ups, glitches, usability problems, advertisements, etc. While studying this phenomenon, the researchers involved realized that more foundational knowledge about the fundamental characteristics of online nuisances and individuals' cognitive, emotional, and behavioral reactions to them had not yet been addressed in prior work. The research agenda was transformed, and a theoretical and empirical approach to studying these issues was adopted. As a result, existing work on CONE is theoretical and evaluative, an exploration of a phenomenon situated in online environments. Some design thinking has been part of work on CONE, but its real value has been to establish a foundation upon which future design activities can rest. Since CONE is a broad model with potential applications across the World Wide Web, scholarly work began with a broad contextual emphasis: online environments. Unfortunately, this context encompassed a vast array of websites and online information systems.

Virtually anything in an online environment can be annoying to some users some of the time. Narrowing context from “online environments where nuisances might occur” to specific websites required an understanding of what kinds of nuisances are most annoying to most users most of the time. To this end, CONE researchers conducted several exploratory studies, consulting with web users via focus groups and surveys. Researchers developed a collection of known online nuisances from three areas: social networking, web-based enterprise resource systems, and online advertisements. Though widely varied, these areas guided the process of narrowing context by localizing different kinds of nuisances to specific web information systems. They were chosen because of the many differences between them.

In the areas studied, some nuisances contained designed features that tended to be highly annoying to most users (e.g. pop-ups, loud noises, etc.). Other online nuisances manifested from interactions between users and online systems, and users evaluated these nuisances differently depending on their personality, goals, online activities, and many other antecedent factors. For example, some users found certain online content to be irrelevant while others did not. This split between designed nuisances and evaluative nuisances points the way toward new ways of thinking about context when studying CONE. While designed nuisances are annoying no matter what the context, evaluative nuisances may be more context-dependent. It will be worth identifying and exploring different contexts in light of their impacts on how different users appraise nuisances.

These future studies can be bolstered by a course of design, turning CONE into a fully-fledged design science undertaking. For example, CONE researchers may begin thinking about IT artifacts that can capture attention and produce enjoyable experiences for users while excluding annoying design features. They may also begin to design online systems that can mitigate feelings of annoyance for users who have certain goals, personality types, or interests. Keeping in mind the contextual areas already identified in CONE research to date, these artifacts could be situated in social media, enterprise resource management, or online advertising. Many additional areas are also interesting and worth exploring, and existing CONE theorization and evaluation will be a useful guide toward identifying and studying these.

1.3. TEMPO: A Contextualized Design Problem

TEMPO, the Temporally Enabled Map for Presentation, is an interactive, animated map that visualizes spatio-temporal military history information. It was developed as part of a design science research project exploring the intersection of military history, education, visualization, cartography, and classroom technologies. Like *Citizen Sort*, situating TEMPO within a well-understood context helped to establish important design and research constraints.

In military history education, maps are an important component of most learning environments. Maps ostensibly show how military-historical events as they unfold in time and space, yet most military history maps show temporal information poorly even if they show spatial information well. Time information – what “happened” – is usually presented with arrows, unit markers, and other static indicators. Without interactive, dynamic functionality, even the best military historical maps can only approximate temporal information about past events.

TEMPO's context came to be understood through the lens of static vs. dynamic maps, and this lens was turned on a variety of related areas: military history, education, cartography, information visualization, and classroom technologies. By evaluating these contexts with an eye toward improving the display of temporal information in historical maps, TEMPO's designers were able to begin refining context from broad possibilities to specific interests. They were able to begin establishing meaningful design and scholarly constraints.

The notion of classroom technologies was a key area of interest, as it raised a number of research and design oriented questions: 1) What is the definition of a classroom? 2) What form might classroom technologies, especially visualization technologies, take? 3) What are the impacts of visualization technologies on the classroom experience for both instructors and students? This last became a key research question for the TEMPO design science project.

Design researchers carefully considered the forms that different kinds of history classes can take, especially military history classes. A classroom observation and one of the TEMPO researcher's own experiences as a former military history student greatly aided this exploratory work. Lectures remain a popular educational form for historians, so TEMPO researchers eventually chose to direct their design activities toward traditional classroom lecture spaces. Historians often eschew visualization technologies in favor of narrative storytelling, and lectures were an interesting arena in which to explore the impacts of a technological intervention on both students and instructors. Focusing on lectures also created interesting design constraints: TEMPO would be a visualization tool that could accompany but not supplant the lecture, be easy for non-technical educators to use, present information clearly and simply for students, and work well on typical classroom presentation equipment.

By clearly conceptualizing a design problem – the need for dynamic maps in military history education – researchers were able to reach a meaningful understanding of context: the military history classroom lecture. In turn, this context guided the development of key research questions, including a core interest in the classroom experience for both students and instructors.

2. Why Do Partnerships Matter?

Partnerships amongst scholars, designers, domain experts, and research participants are a key mechanism for bringing different perspectives together toward the pursuit of innovative design and impactful scholarship. Each contributor in a design science partnership is uniquely situated to provide special insight into challenging and multi-faceted problems. Yet design science collaborations are also shaped by competing (and sometimes conflicting) goals, interests, perspectives, and human abilities. Just as project outcomes are influenced by contexts and constraints, so they are also shaped by the frictions that can develop between partners.

Many design science models overlook the importance of partnerships, perhaps seeing this as a project management (rather than scholarly) consideration. For researchers who study design science, partnerships may be considered a pragmatic detail, divorced from theory and possibly not of scientific interest. For those who wish to *do* design science, however, understanding how partnerships can impact design-oriented research is very important.

2.1. *Citizen Sort*: Partnering With Student Designers

"We'll hire some students to do the design." This phrase is often heard at the inauguration of complex design science undertakings in academic environments. It is based on a conservative vision of design: designers, guided by empirically derived data, are seen as relatively interchangeable (Fallman, 2003). From this perspective it makes sense to place design undertakings in the hands of talented student practitioners. Good students are often knowledgeable and skilled, and they can work inexpensively, stretching project resources.

Lawson (2005), in describing a view of design as an expert activity, notes that students are not necessarily interchangeable with experts (nor, for that matter, are expert designers interchangeable with each other). The TDE model of design science adopts this expert view of design, acknowledging that different designers will have different impacts on design science projects. This means that student designers, despite being inexpensive to hire, will not work the same way as experts. This can shape design science undertakings in subtle but powerful ways.

Research on well-understood systems is usually uninteresting, so design scientists tend to focus on the creation and study of something new – an act of invention. Conversely, students spend the majority of their time mastering prerequisite fundamentals of a craft: budding software engineers are still learning to program and burgeoning artists are still learning how to manipulate artistic media using software or physical materials. Students are still developing what Lawson (Lawson, 2004, 2005) calls a repertoire of techniques and skills that they can draw upon as designers. In short, students are usually not knowledgeable enough to think as inventively as experts about difficult and novel design problems.

This was the case on the *Citizen Sort* project, where design happened at two levels: ideation, the act of conceptualizing and inventing the systems to be developed, and implementation, the act of turning concepts into functioning IT artifacts. Students were initially meant to be responsible for both of these levels of design, but for the reasons stated above, they were far more successful at implementation than they were at ideation. For example, one student programmer, who wrote a reflective journal on her *Citizen Sort* experience, encapsulated her early feelings about the act of ideation in a design science environment: "Due to the unfamiliar terms and lack of academic background in nature science, I couldn't fully understand what the project is." Hevner (2004) notes how design science undertakings are frequently characterized by unstable requirements, complex dependencies, malleable processes and artifacts, creativity, and teamwork. Most students involved in *Citizen Sort* were challenged by the complexity of inventing research-oriented IT artifacts because of these challenging characteristics and their own lack of design experience.

Student designers are also restrained by their limited exposure to design precedent – knowledge of prior design activity that may be relevant to the context they are working within. On the *Citizen Sort* project, most students had no exposure to the citizen science phenomenon or purposeful games when they began, and only a few had much exposure to entertainment video games. No students had designed any video games for themselves, and none had any serious experience with the biological sciences. Thus, the relevant design precedent from *Citizen Sort's* contextual domains was largely unfamiliar to most of the students working on the project.

This problem could have been partially addressed by having students familiarize themselves with games that could inspire design activity on the project. However, paying students to "play video games," even purposeful games, seemed at the time like a misuse of *Citizen Sort's* resources. In retrospect, a week of playing and critiquing relevant game titles would have been highly beneficial. Students would have been exposed to a significant collection of prior precedent, giving them a base of experience from which to draw as design activity began in earnest. In addition, play/critique sessions would have helped to acculturate the design team, creating a common basis for communication about important design and scholarly concepts: interactive storytelling, level design, flow theory, engagement, motivation, interface design, and more.

Citizen Sort's student design team revealed two key sources of tension for a design science project: the design repertoire of various project members, and their knowledge of prior design and scholarly precedent. In the sense that students have limited backgrounds in both of these areas, the expression, "we'll hire some students to do the design," can be highly problematic. However, hiring experts can come with its own disadvantages, especially cost and lack of familiarity with research environments. Managing these tensions requires an understanding of what students are capable of and what they will require assistance with. On *Citizen Sort*, the team's expert designer took responsibility for most ideation and invention, while student developers addressed the details of implementation.

Note that while involving students in design research collaborations can be challenging for the reasons outlined, it does not necessarily follow that students should not be involved in design science. While *Citizen Sort's* lead designer took responsibility for most ideation and invention, the students involved were highly adept at implementation. Once presented with concrete design directions, they were very capable of defining and developing innovative IT artifacts that exceeded expectations for both functionality and scholarship. The students themselves also benefitted greatly from the *Citizen Sort* project. By the end of *Citizen Sort's* principal design phase, virtually all student developers, having honed their respective crafts for more than a year, were far more capable of thinking and acting like experienced designers and scholars.

2.2. *Citizen Sort*: Partnering With Domain Experts

In addition to student developers, the *Citizen Sort* project also featured collaboration between design scientists (studying engagement, motivation, and the design of purposeful citizen science games) and life scientists (interested in crowdsourcing the taxonomic classification of plants, animals, and insects). As with many design science partnerships, this collaboration had many positive advantages, but also a few sources of friction that were challenging to deal with.

The TDE model was conceptualized for the HCI community, and HCI scholars usually do their work within contexts that are of interest to them. Examples include health care, the home, automotive applications, mobile technologies, organizational settings, and many more. Sometimes HCI scholars are experts in their context of interest, but not always. Even when they are, there can be details of the contextual domain that require expert insight.

Hence the need for domain experts, who bring specialized knowledge to a design science project.

Citizen Sort's design scientists were accomplished system designers who had a good understanding of purposeful game design and the citizen science phenomenon. However, these scholars were not life scientists. To realistically study purposeful games situated within in the life sciences, the *Citizen Sort* design scientists worked with biologists to fill in gaps in their knowledge. This was highly beneficial, allowing *Citizen Sort* to be designed around a realistic scientific activity: the taxonomic classification of plants, animals, and insects. The details of taxonomic classification are highly complex, and expert knowledge was truly required in order to design and study games that would produce meaningful results for these life scientists.

Despite this critical advantage, bringing domain experts into the *Citizen Sort* project created two important challenges to be managed over the course of the project: 1) Domain experts sometimes viewed themselves as clients and the *Citizen Sort* design team as hired developers, and 2) the *Citizen Sort* partnership was not as close as it could have been, making the domain experts seem more like occasional consultants than like true partners. Both of these challenges might be categorized as misunderstandings about the role of domain experts in a design science project.

For example, at one key moment during a review of the game *Happy Match*, domain experts insisted on the inclusion of a game feature where high scoring players could classify a photograph to species and "collect" it. The project's lead designer was thinking of cutting this feature, but the domain experts were adamant that it not be removed. In client work, this is typical; when a customer pays a designer for work, he or she has the right to insist upon certain preferences. *Citizen Sort's* domain experts were not customers and were not compensating the design team. Yet for a brief moment, the domain experts had asserted customer-like authority over the project, insisting on including a feature that the lead designer felt was high cost and extraneous to the main point of the research. In fairness, the *Citizen Sort* designers were building a game that the domain experts hoped to then use in their work. These experts wanted the game to be as effective as possible, and considered the feature under discussion to be critical.

Domain experts are brought into design science projects to provide expert perspectives and knowledge not held by project designers or researchers. Sometimes these perspectives are asserted forcefully, and it is up to the design scientist to work with the domain expert to understand the reasoning behind the perspective. In the *Citizen Sort* example, after much discussion, the domain expert articulated his reasoning in a way that truly connected to the scholarly goals of the project. In the domain expert's opinion, identifying and collecting specimens is the emotional heart of the biological sciences, and he described how as a young boy he would go into the fields with a net to collect specimens and identify them – the start of his career as a naturalist. He and the other domain experts strongly felt the "collection" system would appeal to enthusiast players of the game by interactively replicating the fun of collecting specimens in the field. Since a key research goal was to compare "enthusiast" oriented games to story-driven "gamer" oriented games, this reasoning, once it was articulated with consideration for its impacts on research, made sense. The feature was retained and implemented so that it could be studied further.

Citizen Sort also struggled because the design and research team was not co-located with the naturalist domain experts; these two groups were located almost 1000 miles from each other. This made communication less frequent, misunderstandings more common, and valuable expert knowledge harder to convey, understand, and adopt into *Citizen Sort's* IT artifacts. Early in the project – a critical time for expert knowledge to be included – domain experts were used more like occasional consultants than true partners. Later, the disadvantages of this approach were realized, and one domain expert was deliberately included more and treated more like a partner, with improved collaboration.

On many design science projects it is difficult to find domain experts who are nearby and able to participate as true partners. However, when it is possible to include domain experts as full collaborators, the advantages are well worth it. Partners are less likely to act like customers or clients, and more likely to think beyond the scope of their own expert knowledge to the true research and design goals of the project. Even if domain experts are not co-located with design scientists, immersing them as deeply as possible in the project has many advantages.

2.2. TEMPO: The Designer-Researcher

In addition to considering partnerships between separate individuals, it is also useful to think about how designer and scholar perspectives can co-exist within a single individual: the designer-researcher. This situation has advantages; designer-researchers may be able to holistically understand design science initiatives and balance tradeoffs more effectively than individual partners working in collaboration. At the same time, there is a risk that designer-researchers, depending on their backgrounds, interests, and prejudices, will begin to favor either design or research, but not both equally. It may also be difficult for designer-researchers to evaluate and accept critique of their own design activities in an unbiased and scholarly fashion. Finally, designer-researchers must be careful to take on design tasks only when they are qualified to complete them; it is possible for misguided design attempts to confound scholarly results.

The TEMPO project was an excellent example of the benefits and challenges of working as a designer-researcher. TEMPO was a partnership between two researchers, one of whom also took responsibility for TEMPO's design. During TEMPO's design phase, this designer-researcher, who had a professional background in interactive media development, attended to scholarly theories adopted from the visualization and time geography literature, incorporating some and rejecting others as design progressed. Formative evaluation was also important, and TEMPO's designer observed classroom lectures and consulted with a military historian for design insights. This is the advantage of the designer-researcher mentality: an ability to seamlessly oscillate between the designer and scholarly perspectives, attending to the goals, precedents, and outcomes of each.

At the same time, this situation presented two serious challenges. First, having come from a design background but being relatively new to research, it was tempting for the project's designer to stay within the comfort zone of design. This was especially so since TEMPO was addressing an interesting problem that merited high-quality design work and attention to visual detail. As a result, a relatively large proportion of the time spent on TEMPO was focused on design activity. This allowed the scholars involved to publish work in design-oriented venues (e.g. Prestopnik & Foley, 2011, 2012) but limited their ability to publish results about the impact of visualization technologies on the classroom experience – one of TEMPO's key scholarly goals. Though some evaluation activity (surveys and interviews) directed specifically at classroom experience has occurred, it would be more beneficial still to deploy TEMPO in a classroom and collect data about that experience directly. This summative evaluation activity is more likely to take place now that TEMPO's design is finished.

The second challenge for the designer-researcher is that data from a design science evaluation can often include criticisms and complaints, especially when evaluation is directed toward human-centered aspects of a design. Adopting the perspective of a scholar and welcoming evaluation of TEMPO for the purposes of research was a second challenge for TEMPO's designer-researcher. Rather than defending or justifying design choices, it was more important to accept criticism and critique as a natural part of the scholarly enterprise. Even so, setting aside emotional attachments to designed IT artifacts can be difficult. Awareness of the potential for bias and an ability to feel enthusiasm for research outcomes rather than for specific design decisions is a good defense against loss of objectivity. More formally, the researcher-designer may also wish to include neutral partners during evaluation to ensure that data collection and analysis are undertaken in an unbiased and objective manner, similar to the use of coding partners and inter-rater reliability measures. On the TEMPO project, the second researcher, who had less direct involvement with the design, served this important role.

3. Why Does Theory Matter?

Theories – explanations of how the world works – are perhaps the most important outcome of science. Theories may be descriptive, but can also have the predictive power to explain future outcomes based upon specified conditions. In design science, descriptive and predictive theories are critical guides for design and research. Existing theories help designers and scholars analyze and address problems and questions that matter.

In addition to drawing upon theory, design scientists seek to create new theoretical knowledge about how the world works by designing and studying IT artifacts situated within meaningful contexts. In the TDE model, theory is broadly understood to include expertise, literature on design thinking, domain-specific knowledge, and design precedent in addition to scientific theories per se. With this in mind, the theory stage of the TDE model is both a beginning and an end to design science research: theories can inform design and research as much as spring from them.

3.1. CONE: Design-Oriented Theory

The Coping with Online Nuisance Encounters model (CONE) is a foundational step toward a design science approach to studying online nuisance encounters. Following the critic's approach (evaluation > theory > design), CONE was developed out of exploratory focus group and survey data and framed by two existing psychological theories: 1) the theory of psychological stress coping (Lazarus, 1966; Lazarus & Folkman, 1984), and 2) reactance theory (J. W. Brehm, 1966; S. S. Brehm & Brehm, 1981). Both theories attempt to explain how individuals appraise and react to adverse environmental conditions, stress, and loss of control, but neither is specifically adapted to the "artificial" context of the World Wide Web. CONE blends empirical data and two theories into a context-specific model that helps to explain how people encounter and cope with online nuisances.

Though the CONE project has not yet progressed to the point of implementing an IT artifact, it is easy to see how key theoretical findings and the CONE model itself have important implications for design. Just one example: the CONE model suggests that antecedent factors – the user's goals, desires, abilities, interests, etc. – play an important role in determining whether online content is perceived as a nuisance or not. At the same time, many participants in the evaluation stage of CONE noted concerns about online privacy. This suggests that current tailored content or advertising systems may be mitigating one kind of nuisance (irrelevant content) but exacerbating another (loss of privacy). Moreover, existing tailored content systems tend to aggregate personal information over the long term by finding out what kinds of content people like or have clicked on in the past. The CONE model suggests that these general preferences are just one kind of antecedent factor to be considered. A web user's immediate goals, interests, and activities also impact on how relevant or irrelevant content will seem. In addition, the CONE model predicts that loss of control over the online experience is a significant cause of stress and annoyance.

For a design scientist, this suggests an exciting course of research: the design and study of online information systems that avoid tracking personal information over the long term, instead personalizing content using only immediately available and readily supplied information about the user. Such systems could enhance privacy by doing away with permanent storage of users' online activities or allow users to choose what information they are willing to provide and have stored. Note that this is a "wicked" design problem with real value to end users – designing tailored content systems that capture user attention while aggressively respecting privacy is no easy task. Nonetheless, this design science agenda has the potential to help HCI design scientists better understand online privacy issues and the antecedent factors that influence how users perceive online content. In the case of CONE, the reformulating existing theories into a design-oriented model has made it possible to move forward toward new IT artifact design and development.

3.2. Citizen Sort and TEMPO: Contextualizing and Applying Theory

Early in the design stage of *Citizen Sort*, various scientific theories, along with practical literature and the advice of experts, informed the design of the games *Happy Match* and *Forgotten Island*. For example, Malone (1980)described several heuristics for designing engaging instructional video games. These included well-defined player goals, uncertain outcomes, score-keeping, hidden information, intrinsic and extrinsic fantasies, sensory curiosity, cognitive curiosity, and informative feedback. Even though these heuristics were conceptualized in the context of instructional video games, over the years they have gained broader relevance for other kinds of games.

Recall from chapter six that contrasting points-based gamification to story-based gamification was a key goal of the *Citizen Sort* project. Gamification and collective intelligence theories and thinking were very useful for exploring non-story aspects of gamification (e.g. Deterding, Dixon, Khaled, & Nacke, 2011; Malone, Laubacher, & Dellarocas, 2009; L. von Ahn, 2006; Luis von Ahn, 2009; L. von Ahn & Dabbish, 2008; L. von

Ahn, Shiry, Mihir, Ruoran, & Manuel, 2006). In addition, Malone's (1980) heuristics included important storytelling elements, including fantasy and curiosity. *Citizen Sort's* theory stage was further broadened to include practical literature on how to craft good stories, mostly from the fields of game design and film (e.g. Douglass & Harnden, 1996; Giannetti, 1999; Howard & Mabley, 1993; Russin & Downs, 2003; Schell, 2008; Seger, 2003). Crafting a compelling story also requires expert knowledge, just like other forms of design; *Citizen Sort's* lead designer had a background in filmmaking and storytelling.

Now that *Citizen Sort* has matured to the point of summative evaluation, new theories are helping to guide scholarly output. For example, in upcoming work researchers will empirically test differences in the user experience between *Happy Match* (points-based) and *Forgotten Island* (story-based) by asking participants to play each game under controlled conditions. This evaluative study, informed by the theories already mentioned, will also be framed by a variety of game experience measures. In the future, it may even be possible to refine the knowledge gained from such studies into a scholarly theory or model of story-driven gamification, transforming context-specific knowledge into more generalizable theory.

TEMPO, like *Citizen Sort*, also integrated theory into the design and evaluation stages. Various visualization theories helped to inform TEMPO's design, and these theories, plus others from the field of education, helped to inform its evaluation. Of particular note is the rejection of time-geography theory, a visualization approach that initially seemed highly applicable to TEMPO. Once it was introduced into the design stage, however, time-geography theory proved to be problematic. It was ultimately eliminated as a guiding principle for TEMPO, a necessary step that could not have been perceived until both theory and design were considered in unison.

Most TDE design science projects are likely to mirror *Citizen Sort* or TEMPO, where theory is threaded into the design and evaluation stages as needed. One risk of theorizing on a design science undertaking without simultaneously considering design and evaluation is that adopted theories will collide with practical design realities (as in TEMPO) or that they will turn out to be unhelpful as a frame for scholarly evaluation. However, theorizing without design and evaluative distractions can also be an advantage. In the case of CONE, deep theorization was a necessary first step for exploring a scholarly space that was not yet well understood. It may be that future design and evaluation efforts will force adjustments to the CONE model, but having this model as a guide is an invaluable starting point.

4. Why Does Design Matter?

Design is a core activity of design science. The act of designing an IT artifact allows scholars and designers to develop scores of insights about use scenarios, users, technologies, contexts, and phenomenon. In the TDE model, design and science are understood to be different things. The TDE model is a prescription for design scientists who wish to find ways to pair design activity with scholarly activity.

Many design science models do frame design activities as scientific undertakings. Some IS researchers argue that design can be scholarly when it addresses the right "wicked" problem (e.g. Hevner, 2007; Hevner et al., 2004; Hevner & Zhang, 2011). Others have suggested that design is a scholarly enterprise because acts like sketching are themselves a form of reflection and inquiry (Fallman, 2003) or that designed IT artifacts are instantiations of theory (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll, Singley, & Rosson, 1992; Dillon, 1995).

The TDE model acknowledges the value of these interpretations. Design activity does have many of the characteristics described above, including the ability to instantiate knowledge or theories and an emphasis on reflection and inquiry through prototyping and sketching. Nonetheless, from the TDE perspective, scientific inquiry (seeking ways to understand the world) and design activity (seeking ways to transform the world from its current state to a preferred state) are two separate things. Rather than understanding design as a science or scientific method, it is more useful to explore how design and science can complement and inform each other when conducted in tandem, producing distinct scholarly and design outcomes. The value of scholarly outcomes is well understood by various communities of scientific inquiry. Design outcomes can be equally useful, but are often valued differently by different members of a collaboration and by different kinds of end-users.

4.1. Citizen Sort: IT Artifacts as Valued Outcomes

From a design standpoint, *Citizen Sort's* most important outcome is the deployment of *Forgotten Island*, which tests a unique model for purposeful game design. Most purposeful games are designed around the idea of "gamification," where a real-world activity (e.g. classifying or tagging photographs, folding protein strings) is itself made into a game. This might involve simplistic approaches such as awarding points or badges for effort, but could also include more meaningful gamification such as turning the purposeful activity into a puzzle or learning game. The common ground among these approaches is that the purposeful task remains the game's core mechanic.

Forgotten Island tests a different approach to purposeful game design, dubbed "taskification" (see chapter 6). In the taskification approach, the purposeful activity is embedded into an entertainment-oriented game world as just one mechanic among several. Accomplishing the purposeful task is necessary to make progress in the game, but may not be the most important or most interesting mechanic that the game has to offer (though, ideally, it should still be fun and engaging for players). For example, in *Forgotten Island*, an interactive storyline, delivered over the course of 30 separate interactions with various characters in the game, engages players using fantasy elements, visually impressive worlds, mystery, and other known motivational tactics (Malone & Lepper, 1987). Every story interaction finishes with an implicit promise to the player that future interactions with the next section of the story and the game world will contain even more new and interesting elements. The purposeful activity – taxonomic classification of plants, animals, and insects – is an integral part of the story (a classifier machine is picked up by players early in the game and is later used to resolve a major plot point). In addition, taxonomic classification is designed into the game economy: to make progress to the next story interaction and next round of exploration, players are required to classify photographs for game currency. Early in the game, players do only a few classifications, with the goal of getting them invested in the entertainment experience. Once a player is committed to the game experience, more classifications are required until a fairly large number are necessary to successfully conclude the game. In essence, the taskification approach rewards players with a "real game" as long as they are willing to engage with a story-driven purposeful activity at various points along the way.

Participants who have played *Forgotten Island* have commented that it is, "like playing a real game," a contrast to many purposeful games, which can feel experimental and less rich than more developed game experiences. This is unsurprising: *Forgotten Island* was modeled after point-and-click adventures like *King's Quest* and *Monkey Island*, classic entertainment games that contain no purposeful, "real-world" tasks. *Forgotten Island* was also conceptualized around the idea that, for many, science tasks can be incredibly difficult and even boring. In acknowledging this, the design team was free to create a unique model for gamification that avoids pressuring players into becoming budding scientists. Rather, *Forgotten Island* delivers an entertainment experience where the science activity is largely placed in the background. Over the course of the game, some players may realize they do actually enjoy the science task more than they expected. Many others will continue to prefer entertainment over science, and when the entertainment portion of the game is finished they may move on. However, by creating a pure entertainment experience infused with a palatable science task, it may be possible to capture new kinds of players who would not otherwise consider participating in a citizen science undertaking.

One key disadvantage of the *Forgotten Island* model is the amount of effort required to create a game of this kind. Developing a fully-fledged audio/visual story experience containing puzzles, a rich game world, and well-developed characters, and then tightly integrating these with a purposeful activity is a challenging and resource-intensive undertaking. Under the normal constraints of grant-funded research, it is unlikely that the

Forgotten Island taskification model would be viable for most citizen science projects. However, this model does demonstrate the possibility of embedding purposeful activities into games developed by entertainment-oriented design companies. For example, mainstream games with multi-million dollar budgets often include side quests and mini-activities. In many cases, real-world purposeful activities are as much or more fun than the artificial resource-gathering tasks that game designers have invented. Why not turn side-missions like lock-picking or resource gathering into real scientific tasks? A science fiction space adventure game could easily include real astronomy activities like those of *Galaxy Zoo*, justifying them, for example, under the guise of scanning the stars for war materials. Including real activities in high-budget entertainment games could unlock new sources of commercial funding for research and new marketing opportunities for game companies.

Forgotten Island has value to both designers and scholars. For designers, *Forgotten Island* is now prior precedent – a fully-formed example of a unique and potentially powerful model for gamification. Commercial game designers may come to appreciate how this model can unobtrusively introduce meaningful activities into the play experiences that they devise, creating opportunities for themselves, scientists, and the people who play their games. For scholars, *Forgotten Island* and the *Citizen Sort* project as a whole serve as instantiations of theory (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992; Carroll et al., 1992; Dillon, 1995) and as tools for future research. By designing *Forgotten Island* and a comparison game, *Happy Match*, the *Citizen Sort* designers have demonstrated a unique model of gamification and embedded it into an environment where it can be refined and studied further.

4.2. TEMPO: IT Artifacts as Guideposts for Future Scholarship

The TEMPO project, like *Citizen Sort*, featured design outcomes that were of value to both scholars and designers. TEMPO was designed as a tool for exploring the impacts of visualization technologies on the classroom experience for students and instructors. This is a broad area of interest for many visualization and education researchers, yet many such studies limit their context of inquiry to quantitative data in science, technology, engineering, and math (STEM) subjects.

TEMPO was a deliberate attempt to begin a new stream of visualization scholarship outside of these default contexts. It is true that TEMPO drew upon quantitative spatio-temporal data to visualize ship and aircraft movements. At the same time, TEMPO was designed to accompany a qualitative retelling of the Battle of Midway, blending quantitative and qualitative information into a single presentation. TEMPO also included “pop-up” imagery of battlefield locations, ships, aircraft as a mechanism for showing learners “how it was” to be in the Pacific theatre of war during 1942. These photographs and paintings represented a second stream of qualitative data that would complement the largely quantitatively driven sequence of events in the animation itself.

The humanities have largely gone ignored by visualization researchers, so TEMPO was additionally crafted as a vehicle to explore this neglected context. Military historical events offer unique problems for visualization, including abstract but important concepts like luck and timing. Historical information can also suffer from uncertainty as clues to what happened in the distant past are recovered piecemeal, collected in widely divergent works, and often colored by intervening centuries of human experience. Illustrating abstract military-historical concepts and knowledge uncertainty is an important aspect of historical visualization that can have great value for students of history. Just as it is a useful touchstone for exploring the visualization of qualitative information, TEMPO is also a useful first step in exploring new visualization challenges that appear in unstudied domains of knowledge. Here, design activity has pointed the way toward new scholarly opportunities for HCI and information visualization researchers.

TEMPO also points the way toward a second exciting stream of research: the study of the benefits that can accrue to individuals who create visualizations for themselves. TEMPO is designed around a set of textual data files containing position and travel time data for each ship and aircraft to be animated. When TEMPO is playing, a programmatic loop executes multiple times per second, checking these files for new position data and updating the screen accordingly. Note that TEMPO's data files had to be crafted by hand. This laborious process required that numerous historical resources be consulted and compared against each other to ensure that the data changed accurately over time. In chapter 8, it was noted that the process of collecting information about the Battle of Midway so that it could be formulated into data files for TEMPO held real learning advantages. In short, TEMPO's designer because deeply knowledgeable about this important historical battle through the act of creating a visualization.

This insight into the value of creating visualizations for oneself may be one of the most important design outcomes of the TEMPO project. In the visualization literature, research tends to break down into two key areas: representation and interaction (Yi, Kang, Stasko, & Jacko, 2007). Representation has to do with the way that data is visually represented on the screen, and representational research in IV focuses on new algorithms, techniques, and technologies to produce visual representations of data. The term interaction embodies the dialog that occurs between users of a visual information system and the system itself. Interactions might include filtering data to order it in various ways, drilling down through a display to different levels of detail, zooming, panning, or otherwise manipulating the visual display to achieve the view or perspective that the user is interested in. Of the two emphases, interaction and representation, representation has received by far the most scholarly attention from IV researchers (Chen & Czerwinski, 2000; Ellis & Dix, 2006; Thomas & Cook, 2005; Tory & Möller, 2004; Yi et al., 2007). However, the visualization community has begun to exhibit growing interest in interaction research.

Visualization interactions take place along three dimensions: representational, cognitive, and creative. Representational interactions afford the user opportunities to modify the visual display and organization of data on the screen. Cognitive interactions, described through a variety of cognitive models and theories of visualization (e.g. Card, Mackinlay, & Shneiderman, 1999; Chen, 2003, 2006; Spence, 2001, 2007; Ware, 2004), are the purely mental activities that a user will undertake when working with a visualization. Finally, creative interactions are those where the user actually plays a role in visualizing information for him or herself – the creative act of generating visualizations. For that research which does examine visualization interactions, representational and cognitive interactions receive by far the most attention.

Creative visualization interactions are infrequently studied, but the design activity undertaken for TEMPO suggests that these kinds of interaction can have great benefits for users. Furthermore, TEMPO serves as a guidepost toward a new design science initiative to actively explore creative visualization interactions. In chapter eight, a new system called TEMPO Creator was described. This hypothetical system would allow users to collect historical information, organize it in meaningful ways, and visualize it across spatial and temporal dimensions. TEMPO Creator would address an interesting, "wicked" design problem, and would also enable visualization researchers to explore the benefits and challenges of a tool designed to allow users to visualize information for themselves.

5. Why Does Evaluation Matter?

HCI scholarship relies on evaluation activities to produce new theory and new knowledge. Many times, however, HCI scholars produce what Ellis and Dix (2006) refer to as "I did this and it's cool" studies. These feature usability evaluations that, not speaking strongly to theory and context, often fail to achieve the status of "evaluations for research" (Dix, 2010). That is, they test basic functions and features, but fail to explore deeper questions about an artifact's impact on users and environments. The conservative view of design and the notion of "wicked" problems often underlie this evaluative approach; if a design space presents serious enough challenges, then the technical achievement of producing a functioning artifact is itself a scientific contribution.

The TDE model for design science emphasizes evaluation for the purposes of exploring theory and context. It is not enough to evaluate the IT artifact for basic usability metrics like time on task, cognitive load, or user satisfaction. Though technical achievements can be meaningful scholarly achievements, HCI evaluations for research should also explore social-psychological issues surrounding the interactions between a user and a designed system. Such evaluations can produce scholarly outcomes that are valued by many different scientific communities, including new theories; empirical data about specific contexts, systems, and users; and new knowledge about the "artificial" world around us.

5.1. Citizen Sort and CONE: Formative Evaluations as Research Outcomes

Since *Citizen Sort* is an ongoing research project, data collection and evaluation are still in progress, a reflection of the iterative nature of design science. It would be accurate to describe *Citizen Sort* as having started on the critic's approach (evaluation > design > theory) but having moved back into more traditional realms of theorization and evaluation once most design goals were achieved.

Citizen Sort's first formative evaluation was a series of ten interviews conducted with project leaders and system developers working on existing citizen science projects, namely *Galaxy Zoo*, *eBird*, *What's Invasive*, and *The Great Sunflower Project*. This evaluation also included an analysis of the structure and features of the web technologies supporting these four projects. The purpose was to understand how citizen science projects adopt and implement different kinds of features and technologies – things like message boards, games, and science tools. Interviews and website analysis were supplemented with a broader overview study of 27 different citizen science projects, exploring each one's online presence for notable design features.

Key takeaways included the notion of building vs. buying, where "built" systems (bespoke IT artifacts) tended to be perceived as more motivating for players while off-the-shelf "bought" systems tended to be less motivating, but easier and less expensive to deploy.

Zhang and von Dran's (2001) discussion of "satisfiers" and "motivators" was a useful framework for this study. As with many formative evaluations in a design science setting, these results proved to be interesting to members of the scholarly community (see Prestopnik & Crowston, 2012a). Here, formative evaluation informed design activity but also improved our scientific understanding of the citizen science phenomenon.

A second *Citizen Sort* evaluation (Crowston & Prestopnik, 2013) further demonstrates the iterative nature of design science and the scholarly value of formative evaluations. Amazon Mechanical Turk (AMT), a micropayment system where participants are paid small amounts of money to complete simple tasks, was used to evaluate *Happy Match*. 227 participants were paid $0.50 to play this game and provide feedback via a survey. This evaluation was useful for design purposes, suggesting various system improvements and testing the stability of the game. It also produced interesting scholarly results about the quality of data generated by purposeful gamers, providing an early indication of how question wording, tutorial text, and example imagery can impact data quality in citizen science games.

Both of these evaluations show how TDE design scientists can be well-served by maintaining several different perspectives on a project at the same time. A high-level and holistic view of the entire project ensures that core design and scholarly interests are being planned for and addressed, but a narrower "local" view of individual project elements – specific evaluations, theorizations, or design outcomes – can also be useful. Several of *Citizen Sort's* formative evaluations were turned into published scholarly work, even though they were primarily directed toward defining or improving the design of IT artifacts

(Crowston & Prestopnik, 2013; Crowston, Prestopnik, & Wiggins, 2012; Prestopnik & Crowston, 2012a, 2012b). While secondary to the project's main goals, these various evaluations still produced useful scientific findings. By itself, a holistic design science view might suggest that publishing formative evaluations is a distraction, and that their real purpose is to inform design. The "local" perspective belies this attitude, exposing various opportunities to produce valuable scholarly outcomes. This is a key benefit of the TDE model: iteration through the model's theory, design, and evaluation stages with attention to both design and scholarly outcomes makes it possible to produce scholarly work at many different points of a project. This is an important difference from other models of design science (e.g. Carroll, 1997; Carroll & Campbell, 1989; Järvinen, 2007; Nunamaker, Chen, & Purdin, 1990), which tend to favor summative evaluations or technical achievements as a source of scholarly insight.

The CONE project is another clear example of formative evaluations as scholarly outcomes. Focus groups and an online survey were used to inform CONE researchers about the characteristics of online nuisances and the ways that people encounter, appraise, and cope with them. Chapter seven showcases one scholarly paper developed out of this formative work, and preliminary findings have been previously published as well (Prestopnik & Zhang, 2010). CONE's evaluations were always intended to be publishable science, but as has been discussed previously, they also serve an important formative role as work progresses toward design outcomes.

A real strength of CONE's evaluation activity is that it is theoretically driven, directed toward adopting psychological theories, exploring them with empirical data, and producing new theory. This theoretical orientation can underlie any future design activity on the project, making it possible to study resulting artifacts for more than just for their utility or functionality – a fundamental goal of design science.

5.2. TEMPO and CONE: Design Evaluation vs. Scholarly Evaluation

Not all summative evaluations are of interest to scholars. Dix (Dix, 2010), for example, critiques many HCI evaluation practices as "usability evaluations" instead of scientific "evaluations for research." There is a difference between evaluation for the purposes of design and evaluation for the purpose of producing scholarly findings and contributions to theory.

The TEMPO and CONE projects help demonstrate the difference between design evaluation and scholarly evaluation. TEMPO features several design-oriented evaluations directed at a fairly complete IT artifact (the TEMPO visualization tool), while CONE features research evaluations directed at a theoretical model of online nuisance encounters (the CONE model). TEMPO, like CONE, will eventually include evaluations directed toward theory. Similarly, the CONE model may lead to a course of design and design-oriented evaluations directed at whatever IT artifact is produced.

Why are TEMPO evaluations more design-oriented than scholarly? TEMPO's summative evaluations to date have been undertaken outside of the context for which TEMPO was envisioned. They include an expert review with a military history lecturer, an online survey directed at college history instructors, and an online survey directed at non-historians (i.e. potential students). Note that none of these evaluations were situated within TEMPO's envisioned use case: the military history lecture. Rather, the expert review took place after a brief demonstration, and the surveys were issued after participants had used TEMPO for themselves online with no lecture accompaniment of any kind. Thus all three evaluations are divorced from context.

Without the ability to test the theories that informed TEMPO's design or to generate new theory on the use of visualizations in the lecture classroom, the TEMPO evaluations are more useful for their design insights than for their scholarly results. In design evaluations, the loss of context is still a concern, but many of the perspectives collected from study participants can nonetheless inform design improvements and new TEMPO iterations. In addition, while the sample sizes of a single expert review or small survey can be problematic from a scholarly standpoint, for designers this is less of an issue. One interesting insight provided by a single participant can lead a designer to new ideas and an improved design.

It should be noted that despite the design orientation of TEMPO's evaluation phase, researchers still published two scholarly papers about this system. These papers focused on design thinking and were published in an education technology conference (Prestopnik & Foley, 2011) and a educational design journal (Prestopnik & Foley, 2012). As with *Citizen Sort*, the flexibility of the TDE design science process allowed TEMPO researchers to produce scholarship about interesting issues outside the main scope of the project as a whole.

Why are CONE evaluations more scholarly than design-oriented? CONE's evaluations, a series of focus groups and an online survey taken by almost 300 participants, were specifically directed at exploring two existing theories and generating a new theoretical model of online nuisance interactions. With an eye toward future design, these evaluations also set the stage for more robust summative evaluations targeting designed IT artifacts informed by the CONE model. Note, however, that the CONE evaluations to date were not targeted at improving any specific design. The insights they produced are relevant to designers, but not necessarily enough on their own to suggest obvious design strategies or constraints that would help a designer begin creating a functional system to explore online nuisances. The CONE data are suggestive, but not yet directive.

Just as TEMPO would benefit from a more theory-driven round of evaluation, so CONE would benefit from more design-oriented study. These would take very different forms. TEMPO, as a completed IT artifact, must be tested within its intended context and with an eye toward theories of learning or visualization. This could take the form of a demonstration lecture with accompanying observations, focus group discussions, surveys, or interviews. CONE, as a theoretical model, would benefit from a course of concrete, user-based design activity. This might entail a co-design session where web users meet and design online advertisements or social media systems that will avoid creating negative emotions and feelings of annoyance even as they retain their value for users, online marketers, and other stakeholders.

6. Why Does the Theory, Design, and Evaluation Model Matter?

6.1. TDE and Other Design Science Models

The TDE model adopts many ideas from other models of design science. Like Hevner's (2007) three-cycle view, which notes the importance of relevance, design, and rigor stages to research, the TDE model emphasizes three comparable stages of its own: theory, design, and evaluation. Like Peffers et al. (2007), the TDE model emphasizes iteration and the utility of various entry points to these stages. Some have argued how design science is like action research (Cole, Purao, Rossi, & Sein, 2005; Järvinen, 2007), and the TDE model is accepting of this possibility. For example, the TEMPO project was developed with the guidance of educators as a classroom intervention, an action-oriented approach. Others view IT artifacts as instantiations of theory (Carroll, 1997; Carroll & Campbell, 1989; Carroll & Rosson, 1992, 2006; Carroll et al., 1992), and the TDE model can accommodate this perspective as well. For example, *Forgotten Island* demonstrated new approaches to purposeful game design that are, in a sense, models for engaging players. Forlizzi and Zimmerman (2008; Forlizzi, Zimmerman, & Stolterman, 2009; Zimmerman & Forlizzi, 2008; Zimmerman, Forlizzi, & Evenson, 2007; Zimmerman, Stolterman, & Forlizzi, 2010) suggest that design science's real value is as a coordinator of different perspectives. The TDE model goes further, but notes how different kinds of design science partnerships benefit the scholarly enterprise even as they create challenging frictions to manage and overcome. Finally, design is noted by some as a form of inquiry (Fallman, 2003). This is so, and the TDE model is oriented around the desire to reflect and engage with creative and sometimes non-empirical design activities as a mechanism for producing new knowledge.

With all of this in mind, one key value of the TDE model is that it synthesizes concepts from many other design science perspectives into a holistic view, describing constructs and processes that are important to pairing meaningful design with impactful scholarship. Constructs include context and constraints, partnerships, friction, theory, design, evaluation, prior precedent (both design and scholarly), and users. Processes include the various entry points to research, iteration, and knowledge dissemination via scholarly publication and distribution of a functional IT artifact. Though these concepts are addressed in one way or another throughout the design science literature, existing models of design science typically do not address all them simultaneously.

6.2. Defining Design

Not all design science scholars define design the same way. In chapter two, four different views of design were reviewed, including the conservative, pragmatic, romantic, and expert. Many process-oriented design science models explicitly or implicitly adopt a conservative perspective, where design is rigidly defined as an empirically-driven activity akin to engineering. This leads scholars to envision models of design science where IT artifacts are designed according to the best prescriptions of data to solve "wicked" design problems. Solutions to such problems are difficult enough to accomplish that they can be considered scientific achievements in their own right.

The TDE model adopts the expert view of design, which balances empirical and theoretical knowledge against a designer's own expertise and experience, including their repertoire of techniques and knowledge of prior precedent. Designers are individual human beings, and not all design decisions can be made in an optimal fashion based on data alone. Artistic sensibilities, emotional connections, and other factors have been acknowledged by many HCI scholars to be important reasons that people adopt, use, and enjoy many different kinds of computing technologies (e.g. Hassenzahl, 2004; Norman, 2004; Picard, 2003; Shneiderman, 2004; Zhang, 2009). The conservative view can sometimes downplay or ignore this important aspect of design.

Acknowledging the value of design expertise and the role it plays in creative, emotional design, the TDE model defines design science as a complementary partnership between expert design activity and scholarly inquiry. Design activity is shaped by theory and empirical data, but also by a designer's expert knowledge and insights provided by domain experts. Scholarly outcomes are informed by design activity, and result from theoretically-oriented evaluation.

6.3. Iteration

Like other models of design science, the TDE model acknowledges the iterative nature of design science. In the TDE model this manifests with the notion of "approaches." The scholar's approach emphasizes traditional scholarly inquiry (theory plus data) leading to and informing design. The designer's approach emphasizes innovative design as a starting point for later inquiry. The critic's approach emphasizes the identification of problems and challenges as a guide toward design solutions and scholarly insights.

These approaches also identify starting points for design science research and help design scientists stay on track toward culminating moments for their work: a finished artifact, a new theory, or a meaningful empirical finding. As an iterative enterprise, it is possible for design science projects to continue indefinitely as new research questions and design opportunities present themselves. The varying perspectives of designers and researchers, which manifest as different approaches adopted for different projects, help to establish beginning and ending boundaries for design science undertakings.

6.4. Disseminating Outcomes

Like other models of design science, the TDE model emphasizes the importance of outcome dissemination. In the TDE model, outcomes are disseminated through two paths. Scholarly outcomes are disseminated through traditional publication in journals and conferences. These outcomes reach an intended audience of researchers and intellectuals, helping to inform future scholarly efforts. Most models of design science emphasize this dissemination mechanism, but downplay or overlook design processes and the dissemination of artifacts (Fallman, 2003). In the TDE model, the process of disseminating design outcomes (IT artifacts) is as important as the process of disseminating scholarly outcomes. Distribution channels for this include open-access software repositories, app stores, web sites, and the like. For example, the IT artifacts from *Citizen Sort* and TEMPO have been freely released to the public online. Through such channels, an IT artifact may reach hundreds, thousands, or even millions of people – users, scholars, and other designers – who will enjoy and use it.

Normally, the scholarly and design dissemination routes are separate. Scholars publish, speaking to a scholarly community, but their ideas may only reach designers after much time has passed (and sometimes not at all). Designers produce artifacts, but these may only reach the attention of scholars if they become immensely successful (and again, sometimes not at all). The TDE model brings design precedent and existing scholarship together over the course of a research endeavor. Just as scholars publish, so they also draw upon literature when they write. Just as designers produce artifacts, so they also recall other artifacts as precedent when they design. In TDE design science, scholars and designers necessarily work together, exposing each to prior precedent from both the scholarly and design communities.

6.5. Bringing Design and Science Together: Practicalities

The TDE model is a conceptual guide for approaching inquiry through design science. Yet the day-to-day activities of design science can feel far removed from theoretical models. Many practical concerns interfere with idealized notions of how to bring design and scholarship together, and these concerns can have outsized impacts on project outcomes. Most design science models tend to avoid too much discussion of the practical concerns that impact our ability to undertake design and science together, but the TDE model acknowledges the frictions and challenges that can occur in complex spaces of inquiry. A number of practical findings from the three design science examples have been detailed in this chapter. The following table summarizes key practical lessons for TDE design scientists:

	Design and Science In Practice Lessons and Findings
Context	Design science relies on constraints developed out of a well understood context 1. Establishing context is a key early goal for design scientists 2. Context-driven constraints can help to narrow both research goals and design goals
Partnerships	Partnerships, while useful, are also a key source of friction. For example: 1. Student designers do not always approach design activities like experts 2. Domain experts are valued partners, but have their own goals which must be effectively managed 3. Designer-researchers are well-positioned to manage both scholarly and design activities, but must be careful to devote equal attention to each
IT Artifacts	IT Artifacts are valued outcomes of design science 1. Design Science IT Artifacts have their own independent value, especially for users who reside within the problem space being addressed 2. IT Artifacts also help to situate and test theory in specified contexts and applied settings 3. IT Artifacts can be important guideposts toward the generation of new theory
Theory	Theories are valued scholarly outcomes of design science 1. Creating theory is often regarded as key goal of scientific inquiry 2. In design science, new and existing theories can also be important guideposts for future design 3. Theory can be a mechanism for turning context-specific (practice-based) design knowledge into more generalized and scientific forms of knowledge
Evaluation	Evaluation, both formal and informal, is an ongoing activity over the course of a design science project 1. Even formative design evaluations can produce interesting scholarly results 2. However, there are important differences between design evaluations and scholarly evaluations that must be respected

Table 9.1. Design and science in practice. A summary of practical lessons learned from TDE design science projects.

7. Research Questions Revisited

Ostensibly, research is a neat, orderly, and highly controlled undertaking, conducted procedurally and divorced from context, flexibility, intuition, and ill-definition. Yet virtually all social scientists understand that order and control are better understood as goals to strive for than as the actuality of real scientific study. Countless factors, from time and resources to the people involved, shape the nature of scientific work. For the design scientist, this is especially true. By introducing the creation of an IT artifact into a process of scholarly inquiry, control is usually sacrificed to make way for the realities of context, the constraints imposed by design requirements, and the pragmatic tradeoffs required for implementation.

In chapter one, a thematic research question was proposed: How can the scholarly perspective and the designer perspective complement each other in a unified process of inquiry to produce and disseminate useful knowledge to HCI scholars, designers, and end users? The research described in this dissertation study is an attempt to address it. Chapter two explored a substantial body of literature around science, design, and the merger of the two – design science. Chapter three, an included paper, articulated how theory, design, and evaluation are core components of HCI research. Chapter four built upon the previous chapters by describing the TDE model for design science. Finally, three example projects and the present discussion, demonstrated how the TDE model addresses the thematic research question.

Five subsidiary research questions were also proposed in chapter one. An extensive literature review addressed the first: What are the prevailing views of design adopted by various design science perspectives, and what impact do these have on different existing models of design science? A variety of different views of design, including conservative, romantic, pragmatic, and expert perspectives were evaluated and connected to different visions of design science.

The expert view of design became central to addressing the second subsidiary research question: How do different views of design shape possible responses to the central, thematic research question? The expert perspective guided the development of the TDE model over the course of chapter four. At the same time, existing models of design science, which typically draw upon other design perspectives, were also highly influential.

The example projects helped to address research question three: What tensions result when directing different designer and researcher perspectives toward the common goal of knowledge generation? Differences in perspective between designers and scholars, differences in expertise between different designers, domain expert relationships, and internalized designer-researcher perspectives were all identified as key sources of friction. Of course, resources, deadlines, and project management pressures are significant sources of tension as well.

Examples were also useful in identifying methods that design scientists can use to manage friction, the central point of research question four: How can the designer-researcher manage these tensions? The example projects and discussion showed how variable designer expertise can be addressed by instantiating a design team containing a mix of talents and expertise. Domain expert tensions may be resolved through close partnerships, collaboration, and the notion of "trading zones" (Galison, 1997). For designer-researchers, neutral evaluation partners and careful attention to scholarly and design outcomes can ensure equal emphasis on both.

Finally, the example papers and present discussion help to address research question five: What are some examples of HCI research questions, contexts, problems, and technologies that are of interest to the designer-researcher who adopts design science as a mode of inquiry? *Citizen Sort*, CONE, and TEMPO each showcase different design challenges, HCI scholarship, and innovative technologies that can be part of TDE design science inquiry.

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CHAPTER 10: Future Directions, Limitations, and Conclusion

1. Future Directions

1.1. *Citizen Sort*

The *Citizen Sort* website, *Forgotten Island*, and *Happy Match* are well positioned to demonstrate the value of different approaches to citizen science gamification. These IT artifacts are published online and available for anyone in the world to play. Biology classes are signing up to use the games in educational settings, and members of the general public are registering for accounts as well. Over the coming weeks, months, and even years, these players will produce a data set of online play activities that will benefit HCI scholars interested in engagement, motivation, game experiences, and citizen science data quality. In addition, the *Citizen Sort* artifacts are complemented by an ongoing stream of research exploring various issues in gamification and citizen science.

The design of *Citizen Sort* allows for meaningful laboratory comparisons of two different kinds of gamification: points-based and story-driven. Currently, the *Citizen Sort* research team is developing a research protocol for lab studies comparing the game experiences between these different approaches. In the future, biometric sensors such as electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), electromyography (EMG), galvanic skin response (GSR), and others may be used to further explore how individuals perceive, interact, and react to purposeful games and specific game features.

The *Citizen Sort* project also guides the way toward new opportunities for design and scholarship, including the refinement and study of the *Forgotten Island* approach to story-driven gamification. A key challenge of the *Forgotten* Island approach is how resource-intensive it can be. Partnerships with commercial game design companies are one possible solution. In many commercial games, players are asked to undertake mini-game activities (e.g. scanning solar systems for resources, smithing, lock picking, etc.) to earn money or items of value in the game. Could such activities be substituted with real science or learning tasks? It is possible to envision real-world tasks that could be as engaging as the artificial activities currently embedded into many commercial games.

Finally, another gamification approach not addressed directly in the *Citizen Sort* project may be of interest: pay-to-play. In the pay-to-play approach, gamers play a purely entertainment game, occasionally undertaking purposeful activities between rounds to unlock new levels or game content. Many video game companies have already successfully monetized games in this way, but the pay-to-play approach in a purposeful game setting substitutes scientific activity for money. This is an area well worth exploring, both from a scholarly and a commercial perspective.

1.2. CONE

Several future directions for the Coping with Online Nuisance Encounters model (CONE) have previously been described. CONE takes a holistic approach to the study of online nuisances and online stress coping, an approach that bears further scholarly attention. For example, open questions remain about the antecedent factors that influence our perception of online nuisances and our reactions to them. In addition, more work is necessary to categorize and compare different kinds of nuisances that appear in various online contexts. Finally, the CONE model is the result of two exploratory studies and theorization from the psychology literature. Having been proposed, this model can now stand as a guide for hypothesis development and empirical evaluation. Design activities can be part of this evaluation activity, but need not be; it is possible to evaluate CONE using more traditional research methods.

The design science perspective suggests interesting possibilities, however. Guided by the TDE model, designer-researchers may find it useful to explore the ways that users appraise and cope with two kinds of nuisances: invasions of privacy and irrelevant content. Online systems that respect privacy but still manage to deliver relevant and meaningful content are situated within a challenging but potentially rewarding design space. Advertisers, marketers, web system designers, and users all have a vested interest in creating worthwhile and relevant content, but may have different perspectives on privacy. While designers work to implement systems that meet the needs of all of these stakeholders, scholars would be well positioned to draw upon design, theory, ad evaluation stages of research to explore privacy, relevance, control, freedom, appraisal, and coping.

1.3. TEMPO

Perhaps the most interesting future direction for TEMPO is the design and study of a visualization tool that lets individuals visualize information for themselves. Such a tool could have great value in a variety of learning contexts, from STEM fields to the humanities. It is possible to envision a classroom experience where instructors and students work together to study historical moments, great works of literature, or aspects of the natural world and integrate them into an online visual system where they can be shared and enjoyed by others. For those who actually create visualizations in this manner, many benefits are possible and deserving of further study: enhanced engagement with lesson materials, opportunities for informal learning, improved learning outcomes, and improved collaboration with instructors or classmates. Similar benefits might also be measured for those who eventually use a finished visualization, even if they had no role in creating it. A design science project oriented around a TEMPO Creator system would present many opportunities for theorization, challenging design, and evaluation.

The TEMPO project also raises additional questions of interest to HCI and visualization researchers. For example, to history students, textbooks often seem complete and certain in the historical perspective they present. The reality, however, is that history is deeply uncertain; historical data often comes from fragmentary and incomplete sources, and unearthing even small fragments of new evidence can sometimes radically change the way historians view and understand past events. Understanding uncertainty is a key challenge for historians. At the same time, developing new approaches for visualizing uncertainty is an area of great interest to HCI and visualization scholars. This is an opportune space for design science, where a challenging design problem situated in an interesting context can be complemented by a meaningful research interest.

Another future area of opportunity for TEMPO is the study of qualitative information visualization. The psychological impact of events, decision making, individual personalities of historical figures, and the notions of "initiative" and "friction" in military history are examples of qualitative information found within the historical context. Such information can be visualized at a variety of levels of detail, from highly specific (e.g. the activities of one individual) to extremely broad (e.g. strategic overview of a global event). Just as with uncertain information, HCI and information visualization scholars are also interested in finding ways to visually depict qualitative and abstract information. This offers opportunities for historians and HCI scholars to collaborate in a design science partnership, developing and studying new tools to visualize qualitative historical data.

1.4. The TDE Model

The TDE model has already been discussed at length in this dissertation, but several future directions may be of interest to design science scholars in HCI. The TDE model describes an approach to scholarly inquiry using design, but makes few assertions about the appropriateness of various research methods. For example, it is possible to envision a fit for qualitative, quantitative, and mixed methods work in the design science approach described. A host of research methods, including controlled experiments, surveys, focus groups, interviews, ethnographic field studies, content analysis, talk aloud, participant observation, case studies, black and white box testing, and expert review all potentially have a meaningful place in a design science undertaking. In future work, it will be advantageous to connect these diverse methods to specific stages of a design science project. For example, early stages may be more exploratory, favoring more qualitative approaches like focus groups, interviews, or ethnography. The later stages of research may become more empirical, and methodological approaches could shift to hypothesis testing and experimental techniques. During the design stage, design-oriented methods like testing or expert review could be highly beneficial.

The TDE model is a blend of constructs and processes. A second future direction will be to deconstruct the model and study processes and constructs separately. For example, design science scholars may be interested to look more deeply at the roles of designer, scholar, domain expert, participant, and user. They may also be interested in the various entry and exit points for design science inquiry. Most design science models are steeped in notions of design, but as has been demonstrated, different design scientists define design differently. It will be worthwhile to unpack such constructs to explore how definitions can impact different views of design science. By examining constructs and processes separately, scholars can build a more complete understanding of design science and the TDE model as a whole.

Finally, the TDE model should be applied to new design science projects like those previously described in this research. There are a host of contexts, design problems, and research questions that could productively be studied using this design science approach. In addition the TDE model itself can benefit from such studies as it is refined and improved over time.

2. Contributions and Limitations

This dissertation addresses a key problem in HCI: the challenge of binding design activities to scholarly inquiry. A review of existing literature on scholarly inquiry, design perspectives, and design science in HCI and IS revealed how different scholar and designer outlooks and different perspectives on design can impact design science activities. To date, no one model for design science has authoritatively emerged as dominant; rather a variety of models, approaches, and ideas seem to exhibit various strengths and weaknesses.

In response to this challenge, this work presents a new model for design science: the theory, design, and evaluation model (TDE). This model was developed out of a prior study exploring the HCI community and its variable emphasis on three important stages of research: theory, design, and evaluation. The prior study was included in full as chapter three, a precursor to the formal presentation of the TDE model. Drawing on analysis of prior design science thinking, and containing several unique elements – the parallel conceptualization of design and scholarly activities, the "expert designer" perspective on design, the tension that can occur when design and scholarship are linked – the TDE model offers a roadmap for HCI researchers who wish to engage in design activities, either in collaboration with others or for themselves.

Making comparisons between different models of design science can be difficult; every model has its merits and disadvantages which may only become noticeable during long-term application to many different design and scholarly problems. Arguing that a specific model is "better" or "worse" than any other can be problematic, since arguments for superiority or inferiority can sometimes hinge on highly subjective factors; a model that is well-suited to one scholar's interests or approach may be poorly-suited to another's. This is an important limitation of the present study and of design science thinking in general. However, demonstrating some successful TDE outcomes from specific design contexts and research problems is a critical component of this work.

This dissertation study makes several contributions to the HCI community and the community of interest developing around design science. In the existing design science literature, there is a tendency to assume a perspective on design (usually a conservative perspective with a highly structured, engineering-oriented outlook on design activity) without specifically naming, exploring, or justifying that perspective. This can conceal underlying assumptions which may impact subsequent research developments. Two key contributions of this dissertation are 1) to shed light on different design perspectives as they relate to various models of design science and 2) to situate the TDE model in a disciplinarily useful and unique set of assumptions and perspectives that are thoroughly explained and explored.

The TDE model itself is the major contribution of the research. The TDE model pairs scholarly activities with design activities in a novel and beneficial way. Rather than justifying design as a scholarly activity per se, or emphasizing only the contributions that designers can make to research in terms of perspective, the TDE model treats design and science as related, parity activities: both are necessary to produce good design and scholarly outcomes. The TDE model clarifies confusion that can result when design is argued to be science, or science is poorly fitted into design practice.

The tensions that can exist between designers and scholars in design science often go unacknowledged; the TDE model treats such tensions as both opportunities and challenges. Designer and scholar perspectives differ greatly, yet share a number of similarities. Both designers and scholars draw upon preexisting work (albeit in different ways) and seek to contribute back to those sources of prior precedent. An important contribution of this research is to acknowledge and explore the tensions that exist in design science initiatives, as well as to identify points of commonality between designer and scholarly activities.

Finally, it is not uncommon for scholars to call for good examples of design science work. A major contribution of this research is to present three examples of ongoing design science projects which deal with very different contexts and problems; these demonstrate how the TDE model is a useful framework even for very different kinds of design science projects in human-computer interaction.

3. Conclusion

For good or ill, we live in an artificial world where our daily activities are circumscribed by an almost totally man-made environment. For example, it is possible to travel across an entire continent without ever once stepping outside; this traveler's cocoon raises deep and growing concerns about freedom, privacy, safety, and health. In an age of mobile devices and ubiquitous computing, we can connect with virtually anyone at virtually any time about the most trivial or momentous of matters; in this environment, our attention seems more and more preoccupied. Will we ever be free of the demanding voices on the other end of the phone? Can the time we spend on social media, online videos, and games ever be put to productive use? Our interactions with information technologies and IT artifacts raise challenging questions about human cognitions, behaviors, and emotions.

It is increasingly important for us to comprehensively understand objects, environments, and interfaces, the design activities that lead to their creation, and the human experience that they shape and are shaped by. Examining these elements separately tells part of the story; exploring them in concert reveals more. If we are to fully understand the world we live in – the artificial world of IT artifacts that has become the only world we really know – we must become the best scholars we can while embracing the inner designer that resides within each of us. We must become designer-researchers and researcher-designers. We must become design scientists.

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Zhang, P. (Forthcoming). The Affective Response Model: A Theoretical Framework of Affective Concepts and Their Relationships in the ICT Context. *Management Information Systems Quarterly (MISQ)*.

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Zimmerman, J., & Forlizzi, J. (2008). The Role of Design Artifacts in Design Theory Construction. *Artifact, 2*(1), 41-45.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). *Research through design as a method for interaction design research in HCI*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Zimmerman, J., Stolterman, E., & Forlizzi, J. (2010). *An analysis and critique of Research through Design: towards a formalization of a research approach*. Paper presented at the Proceedings of the 8th ACM Conference on Designing Interactive Systems.

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Education

Ph.D. Syracuse University, Information Science & Technology | *May 2013*

School of Information Studies (Dissertation Title: *Design Science in Human-Computer Interaction: A Model and Three Examples*).

Advisor – Dr. Ping Zhang
Committee – Drs. Alan Foley, Howard Turtle, and Mike D'Eredita
Internal Reader – Dr. Yang Wang
External Reader – Dr. Dan Cosley
Oral Defense Chair – Dr. Michael Schoonmaker

M.Phil. Syracuse University, Information Science | *December 2012*

School of Information Studies (GPA 3.95)

M.S. Syracuse University, New Media | *July 2006*

S.I. Newhouse School of Public Communications (GPA 4.0)

B.A. Syracuse University, Television-Radio-Film Production | *May 2001*

S.I. Newhouse School of Public Communications (Magna Cum Laude)

B.A. Syracuse University, History | *May 2001*

Maxwell School of Citizenship and Public Affairs (Magna Cum Laude)

Research Interests & Experience

Interests

Human-computer interaction, game design, interactive design, information visualization, design science, and the user experience.

Purposeful Gaming for Citizen Science | *September 2010 – Present*

Served as lead designer, project manager, and graduate researcher for an NSF-funded research effort (Grant# 09-68470; Kevin Crowston, PI) exploring purposeful gaming in the context of online, crowdsourced science. I managed a total of 16 student programmers, designers, and researchers in the development of two purposeful games that support the taxonomic classification of plant, animal, and insect species. HCI research goals include exploring participant motivation, engagement, and resulting data quality in the context of citizen science. Project was covered in various media, including *Scientific American* and *National Geographic.*

More information at www.citizensort.org.

Interactive Visualization | *September 2010 – Present*

Designed and evaluated an interactive visualization tool (TEMPO) to enhance the lecture experience for military history instructors and students. Design goals included finding ways to visualize abstract concepts such as luck, timing, and decision-making in battle. Research goals included evaluating TEMPO for its impact on the student and instructor experience.

Publications

Work Under Review / Revision

Prestopnik, N.R. & Zhang, P. Web Nuisance and Annoyance Coping: Empirical Investigations and a Theoretical Model.

Refereed Journal Publications

Prestopnik, N.R. & Foley, A. (2012). Visualizing the Past: The Design of a Temporally Enabled Map for Presentation (TEMPO), *International Journal of Designs for Learning. Vol 3, No 1*.

Prestopnik, N.R. (2010). Theory, Design and Evaluation – (Don't Just) Pick any Two, *AIS Transactions on Human-Computer Interaction* (2) 4, pp. 167-177.

Refereed Conference Proceedings

Prestopnik, N.R. (2013). Cooperative Visualization: A Design Case. *iConference*. Fort Worth, TX, 12–15 February, 2013. (**Winner:** *Lee Dirks Best Paper Award*)

Crowston, K. & Prestopnik, N.R. (2013). Motivation and Data Quality in a Citizen Science Game: A Design Science Evaluation. *Hawaii International Conference on System Sciences (HICSS)*. Wailea, Maui, HI, 7–10 January, 2013.

Prestopnik, N.R. & Crowston, K. (2012). Purposeful Gaming & Socio-Computational Systems: A Citizen Science Design Case. *ACM Group: International Conference on Supporting Group Work*. Sanibel Is., FL, 27–31 October, 2012.

Prestopnik, N.R. & Crowston, K. (2012). Citizen Science System Assemblages: Toward Greater Understanding of Technologies to Support Crowdsourced Science. *iConference*. Toronto, ON, Canada, 8–11 February, 2012.

Prestopnik, N.R. & Crowston, K. (2011). Gaming for (Citizen) Science: Exploring Motivation and Data Quality in the Context of Crowdsourced Science through the Design and Evaluation of a Social-Computational System, *7th IEEE International Conference on e-Science*. Stockholm, Sweden, 6–8 December, 2011.

Prestopnik, N.R. & Foley, A. (2011). The TEMPO of Battle: Designing a Temporally Enabled Map for Presentation, *ED-MEDIA*. Lisbon, Portugal, 27 June–1 July, 2011.

Prestopnik, N.R. & Zhang, P. (2010). Coping With Nuisances on the Web. *16th Americas Conference on Information Systems.* Lima, Peru, 12–15 Aug, 2010. (**Nominated:** *Best Paper Award*)

Refereed Book Sections

Prestopnik, N.R. & Zhang, P. (2012 Forthcoming). Human Computer Interfaces (HCI): Interactivity, Immersion and Invisibility as New Extensions, in D. Straub and R. Welke (eds.), *Encyclopedia on Management Information Systems, 3rd Edition,* Wiley.

Refereed Conference Posters and Extended Abstracts

Prestopnik, N.R. and Souid, D. (2013). Forgotten Island: A Story-Driven Citizen Science Adventure. *ACM SIGCHI Conference on Human Factors in Computing Systems (CHI)*. Paris, France, April 27 – May 2, 2013 (Forthcoming).

Crowston, K., Prestopnik, N.R. & Wiggins, A. (2012). Motivating Citizen Scientists with a Classification Game. *Conference on Public Participation in Scientific Research*. Portland, OR, 4–5 August, 2012.

Prestopnik, N.R. (2011). Information Spaces as Interactive Worlds. *iConference*. Seattle,WA, 8–11 February, 2011.

Editorially Reviewed Book Chapters

Alten, S.R. (2008). Audio in Media, Ninth Edition. Boston, MA: Wadsworth. (Chapter 17, *Audio for Interactive Media: Game Sound*, drafted by N.R. Prestopnik for 8th and 9th editions).

Alten, S.R. (2008). Audio in Media, Ninth Edition. Boston, MA: Wadsworth. (Chapter 18, *Internet Production*, drafted by N.R. Prestopnik for 8th and 9th editions).

Editorially Reviewed Publications

Prestopnik, N.R. (2009). Q n A: Realistic Outdoor Lighting Techniques for TrueSpace. *3D World*, (120), 88.

Prestopnik, N.R. (2009). Q n A: Using 3D Particle Systems to Simulate a Laser Effect. *3D World*, (115), 78.

Prestopnik, N. (2009). Q n A: Designing an Underwater Scene in TrueSpace. *3D World*, (112), 77.

Prestopnik, N.R. (2008). Modeling on Rails. *3D World*, (109), 58-59.

Teaching Experience

Instructor of Record

Writing & Designing for Interactive Media | *Spring 2008*
Adjunct Instructor at Syracuse University for web and interactive design course (part of the Department of Defense Advanced Visual Information Program). Developed a syllabus which included the following topics: XHTML, CSS, Graphic Design, Flash, Usability in Interactive Systems, and Information Architecture.

Computer Animation (2 Semesters) | *Summer 2000, Winter 2001*
Adjunct Instructor at Fulton-Montgomery Community College for two sections of an introductory 3D computer graphics course. Developed a syllabus which included the following topics: modeling, shading, lighting, and basic animation.

Co-Instructor

Social Web Technologies | *Spring 2010*
Second instructor at Syracuse University where I co-taught one section of a social web technologies course as part of a teaching practicum for credit. Instructed and guided students as they developed websites with a social-computational focus, such as crowdsourced recommendation services, collaborative art, and ride sharing.

Scripting for Games | *Spring 2010*

Second instructor at Syracuse University where I co-taught one section of a game scripting course as part of a teaching practicum for credit. Instructed and guided students as they developed web-based games using XHTML, CSS, and JavaScript.

Teaching Assistant

Writing & Designing for Interactive Media | *Spring 2006*

Teaching Assistant at Syracuse University for two sections of a web and interactive design course. Topics included HTML, CSS, Graphic Design, Flash, Usability in Interactive Systems, and Information Architecture. I later taught a section of this course in spring 2008.

Music Underscoring | *Spring 2006*

Teaching Assistant at Syracuse University for one section of a music underscoring course. Taught labs and assisted students with recording, mixing, and editing.

Advanced Audio | *Spring 2006*

Teaching Assistant at Syracuse University for one section of an advanced audio course. Assisted students with advanced audio projects.

Sound Production | *Fall 2005*

Teaching Assistant at Syracuse University for two sections of a sound production course. Taught more than 10 lab sessions (4-5 students each) and trained students in the use of audio technology and the practical application of audio concepts covered in class.

Guest Lecturer

Human-Computer Interaction | *Spring 2012*

Invited speaker at Syracuse University for two sections (undergraduate and graduate) of a course on human-computer interaction. Gave a prepared talk about my visualization research and the TEMPO tool I designed for military history education.

Cyberinfrastructure | *Fall 2011*

Guest lecturer at Syracuse University for one session of a graduate level (IST 600) course on cyberinfrastructure. Designed a seminar discussion on information visualization and visualization technologies.

Multimedia Computing | *Fall 2011*

Guest lecturer at Morrisville State College for one session of an undergraduate level (CITA 410) course on multimedia computing. Developed and delivered a lecture on video production, including visual composition, camera movement, and the emotive and informational effects of visual choices in film and video production. Designed an accompanying lab where students practiced the variety of techniques shown in lecture.

Academic Service

Service to Scholarly Community

Journal and Conference Reviewing

- Computers and Education
- Transactions on Human-Computer Interaction
- ACM Conference on Computer Supported Cooperative Work
- International Conference on Information Systems
- iConference

Service to Syracuse University

University-Wide Service

- Global Game Jam Organizing Committee, SU Event Site (2012, 2013)

Syracuse University School of Information Studies

- Doctoral Programs Retreat Committee (2012)
- Personnel Committee (2011 – 2012)
- Doctoral Programs Task Force (2011)
- Undergraduate Committee (2010 – 2011)
- Peer Advisor to the 2010 PhD Cohort (2010 – 2011)
- Strategic Faculty Search Committee (2010)
- Doctoral Programs Committee (2009 – 2010)

Service to Morrisville State College

College-Wide Service

- Morrisville State College Faculty Congress, Ex Officio Member (2007 – 2009)
- Web Advisory Group, Chair (2006 – 2009)
- Web Advisory Dean's Group, Chair (2006 – 2009)
- College Judicial Board (2008 – 2009)
- Crisis Communication Team (2007 – 2009)
- Community Service Initiative Committee (2007 – 2009)
- Hiring Committees for Web-Related Positions (2006 – 2009)
- Review Committee, Web Development Bachelor Degree Program (2009)

Technology Services Department

- Technology Services Laptop Scholarship/Award Committee (2007 – 2009)

Interactive Design Experience

Morrisville State College, State University of New York, Morrisville, NY

Interactive Design Consultant | *September 2009 – September 2011*
After concluding my full-time employment at Morrisville State College to pursue my PhD, I continued to work with the school as a consultant. I led a college-wide video production initiative, writing, shooting, and editing more than 150 short videos to promote the school and its unique educational vision. I also worked with senior administrators and web designers to strategize the college's creative and technical approach for the web.

Web Administrator | *June 2006 – August 2009*
Working with the college president, administrators, deans, faculty, staff, and students, I established a creative vision for the college's web environment and shepherded that vision from concept to implementation and launch. During my tenure as web administrator, I established information architecture, created engaging user experiences, and developed a consistent and effective design language for virtually all of the college's more than 70 public and internal websites. Furthermore, by employing user testing and aggressively incorporating user feedback, I designed and developed a highly effective CMS system to support the college's extensive front-end web infrastructure. This CMS, developed in ASP.NET, is still in use at the college today. Finally, I managed the college's web development department, supervising web design staff, liaising with technologists for networking and systems administration, establishing and managing department policy, and sitting on hiring committees for various web-related positions.

Imperial Solutions, Syracuse, NY

Owner / Freelance Designer | *2000 – Present*
As a practicing interactive designer, I have designed creative user experiences, attention-grabbing visuals, and consistently reliable web systems on a freelance basis for numerous clients. I am always eager to learn new tools, technologies, and techniques. Portfolio available at *www.imperialsolutions.com*.

ICOM, Clifton Park, NY

Art Director | *November 2003 – June 2005*
I leveraged my design background and technical experience to lead ICOM's locally and regionally focused web design department. Equal parts creative, technical, and managerial, this position gave me an opportunity to hone my visual sense, establish a strong working knowledge of web programming (primarily ASP classic), and supervise client web projects from start to finish.

Make-Up Artist Magazine, Los Angeles, CA

Multimedia Director | *April 2002 – October 2003*
In this position I combined my interest in film production and special effects with my interactive design experience. I redesigned the company website from the ground up, authored DVDs, and established myself as the magazine's primary layout artist. This work culminated in a 2003 redesign, where the managing editor and I worked as a team to establish a brand new design language and layout for the magazine. Another major accomplishment was to oversee video production for the Make-Up Artist Trade Show, an industry event attended by film and television make-up professionals, including numerous Academy and Emmy Award winners.

Fulton-Montgomery Community College, Johnstown, NY

Lab Consultant | *Summer 2000, Summer & Fall 2001*
In this support position, I conducted faculty training and worked on computer animation projects, video production, CD-ROM development, graphic design projects, and website development.

Maxwell School of Citizenship and Public Affairs, Syracuse, NY

Lead Lab Consultant | *May 1999 – May 2001*
In this position I worked on computer animation projects, designed faculty training modules, produced video projects, and built websites.

Creative and Technical Skills

Writing (scientific, professional, technical, creative), interactive design, user experience design, game design, information architecture, website design, graphic design, information visualization, 2D/3D computer graphics, audio/video production, Flash, HTML5/XHTML, CSS, database design, and web application programming using ASP.NET, ASP, PHP, JavaScript, ActionScript3, jQuery, AJAX, & SQL.

Honors, Awards & Distinctions

Academic & Professional Honors

Lee Dirks Best Paper Award Winner, iConference 2013 (2013)
Grand Prize Winner, SU Student App Competition for *Citizen Sort* (2012)
Best Paper Nomination, AMCIS 2010 (2010)
Future Professoriate Program, 2 Year Stipend (2009, 2010)
TrueSpace 3D Artwork Gallery 1st Place, 2nd Place, and over 15 Honorable Mentions (2000-2008)
SUNY/CUAD Awards for Excellence Program (2007)
S.I. Newhouse School of Public Communications Summer Fellowship for Graduate Study (2006)
TrueSpace Computer Animation Contest; 2nd place accident reconstruction animation produced for Crowsey, Inc. (2004)
S.U. University Honors, Magna Cum Laude (2001)
S.U. Faculty Advising Committee (2001)
Golden Key National Honor Society (2001)
S.U. Chauncey Horton Memorial Award (2001)
S.U. Dean's List, Eight Consecutive Semesters (1997-2001)
S.U. Honors Program (1997-2001)
S.U. Chancellor's Scholar (1997)
National Council of Teachers of English National Writing Award (1997)
Barbara Moynehan Excellence in Writing Award (1997)
Computer and Technology Scholarship (1997)