Design-Based Research Methods and Theory Building: A Case Study of Research with *SpeakEasy*

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Design-based research methods are an emerging research paradigm that blends empirical research with design and implementation. This article discusses how a design-based research trajectory can help not only suggest and refine theories, but also permit their falsification. In a series of design-based research studies on an online discussion tool (called *SpeakEasy*), the author shows how a theory of *socially relevant representations* for learning was formed, applied, refined, and ultimately tested.

As described in the introductory article in this special issue, design-based research methods (DBRM) in education are an exciting, productive set of research methods that blend a design stance with empirical research in context to advance our theoretical knowledge of learning, while simultaneously producing valued educational outcomes for learners in real settings (Design-Based Research Collective, 2003; Kelly, 2003). In this article, I describe the development of an online discussion tool for learning, called *SpeakEasy* (Hoadley, Hsi, & Berman, 1995a), and discuss how a long trajectory of design-based research not only allowed theory to inform design, but also enabled design to inform psychological theory (Hoadley, 2002, in press). One noteworthy aspect of this story is that the design-based research paradigm permitted not only evaluative research and hypothesis formation to take place, but also allowed careful refinement and testing of a new psychological theory, the theory of *socially relevant representations (SRRs)* for learning (Hoadley, 1999a; Hoadley & Kirby, 2004).

In the sections below, I describe some of the initial design goals, early designs of the predecessor to the *SpeakEasy* software and associated educational activities, and the theories used to construct these designs.* Then, I describe how early studies led to development and refinement of the theory of SRRs. Finally, I discuss how later DBR studies allowed testing of the theory and delineate some of the implications of this research trajectory for DBRM in general.

SpeakEasy and Its Predecessor, the *Multimedia Forum Kiosk*

In 1992, the Web was still an idea more than a reality. Multimedia was novel and expanding onto the computing scene. Educational CD-ROMs were becoming more important, and video online was no longer restricted to specialized videodisc or high-end workstations for the first time. Though the Web was basically unknown, the Internet was not; e-mail and Usenet newsgroups were beginning to ascend in popularity not only with academic computer scientists, but also with college students, businesspeople, and home users through services like Prodigy and AOL. At that time, Sherry Hsi, Christina Schwarz, and I began work on an online multimedia discussion tool called the *Multimedia Forum Kiosk*. We had a simple core design goal: To create a tool that would allow collaborative knowledge building while taking advantage of multimedia. We wanted something that would be "better than Netnews" (our unofficial mantra) by supporting higher quality, more coherent discourse through a more intuitive graphical user interface. We also identified as one of our use-case scenarios the collaborative qualitative analysis or discussion of video data. Implicitly, our dissatisfaction with Usenet newsgroups hinted at a tacit goal we shared: building a system that would promote greater social connectedness rather than disconnection.

Our initial system, built in *HyperCard*, drew on some examples we were familiar with, namely a video bulletin board that Sherry had helped develop at the Apple Multimedia Lab (for a much later write-up of this design's evolution, see Bellamy, Woolsey, & Kerns, 1995), and Scardamalia and Bereiter's *CSILE (Com-*

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*More information about the design of the *SpeakEasy* and its predecessor, the *Multimedia Forum Kiosk,* is available elsewhere (Hoadley, 1999a, 2002, in press; Hoadley & Hsi, 1993; Hoadley *et al.*, 1995a).

puter-Supported Intentional Learning Environments) software (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989). We admired the Apple project's use of the brand-new QuickTime multimedia technology, although it depended on an expensive, specialized hardware setup to allow video capture to make postings. We also were influenced by Scardamalia and Bereiter's use of scaffolding to improve the quality of discussion in their tool. Taking both strategies to heart, we created a kiosk-based bulletin board system. Unlike Netnews, which was subject-based, our tool was topically based, with all participation centered on a question or discussion point posed by a topic author.

The *Multimedia Forum Kiosk* system had two main interfaces. The *opinion area* provided a welcome to the topic; and, in addition to presenting the topic author's motivating question, it supplied a representation of all of the participants in that topic's discussion and their points of view (revisable over time, but only one opinion per person), showing a community gestalt. The *discussion area* was more similar to what we now are accustomed to as threaded discussion. It provided a chance for people to post comments and respond to one another, with a graphical tree structure (rather than a outline-based view, this was truly tree-like). Similar to CSILE's "think types," each comment subtitled with a *semantic label* (such as "and," "but," "or," "?" and so on) that identified how the comment related to prior ones.

In our system, we used multimedia in various innovative ways. Topics could include short video clips as a conversation starter. Topics, opinions, and comments were individually authored; and picture icons were used to highlight this authorship. Two design decisions that were byproducts of our technological constraints were the fact that the system was a same-place, different-time system (due to limited networks for sharing large files); and that users were permitted to log in anonymously. Because of the photo icons and the relative difficulty of obtaining and digitizing images of users, the kiosk had some guest accounts to allow use of the system by people who had not been previously photographed and set up with accounts.

Designing from Theory and Our Early Evaluation Work

Initially our designs were based upon theories of collaboration and learning. Our emphasis on collaboration came from Vygotskian notions of co-construction and collaboration (Newman, Griffin, & Cole, 1989; Wertsch, 1979, 1985), but more specifically we used ideas about knowledge-building communities (Scardamalia & Bereiter, 1991, 1993) and communities of practice (Lave & Wenger, 1991) to guide our vision of successful use of the system. Later, two more theories were significant influences. We came across work on small-group interaction that framed the types of discursive moves typically taken in collaboration; this supported and extended our semantic labels (Bales, 1969). We also followed Pea's more specific theories of the mechanisms for learning through collaborative discussion (Pea, 1993a, 1993b). This theory helped us focus on process support, instead of merely focusing on usability of the system; we emphasized developing social supports that worked in conjunction with the software to produce certain kinds of interaction that constituted "productive discourse."

As is typical, these theories did not completely specify what types of design decisions we should undertake, either in the interface or in the surrounding activities. Should we permit anonymity? What types of group size would best help learning? What types of questions, topics, or adult moderation might best engender "productive discussion"? None of these questions could be answered from first principles with the theories at hand, but we drew on our own and expert intuitions (including expert designers at Apple, Taligent, Interval Research, and elsewhere) for guidance and used iterative refinement to develop workable educational interventions using prototypes of the tool.

At this point, we used both formative evaluation and iterative refinement just to get something working in practice. We tried our tool in a wide variety of contexts, including graduate courses in engineering, an informal lounge in an education department, science museums, a self-paced study center, and (in what would eventually become our primary research context) a middle school physics classroom. In this context, we ended up supporting an inquiry-based science curriculum through students' discussing topics that asked them to explain science phenomena, presented through multimedia (Bell, Davis, & Linn, 1995; Hoadley & Bell, 1996). We eventually arrived at a very stable set of activities based on this particular learning context.

Some of our early findings centered on the importance of the context of use. We began with basic usability studies—our software fit the HCI "ten minute rule" (meaning that novices could walk up and use the system without any training, uncovering all its features in ten minutes or less). But usability is only one component of the success of such a system, and we began to understand how important the activities and context of use were for us. For example, when we used the system with engineering students to help assess learning climate issues, we discovered through comparison of different courses that physical access to the system was important, but more important was the degree to which the course instructor showed evidence of incorporating feedback provided by students. One particularly interesting example involved a non-native

speaker of English; this student reported that the *MFK* made a big difference in his own learning climate, because—unlike in face-to-face interaction in the class—he could compose and edit contributions to class discussions on his own time (Hsi & Hoadley, 1995). We later demonstrated with the middle-school science students that identity, gender, anonymity, and online participation played an important role not only in students' participation in the discussion, but also in their learning (Hsi & Hoadley, 1997).

As the next stage of our design-based research and building on this work, prior to the introduction of the first Netscape browser, we developed the second ever Web-based threaded discussion tool,* called *SpeakEasy* (Hoadley *et al.*, 1995a). *SpeakEasy* retained most of the *Multimedia Forum Kiosk* interface; but, because it was Web-based, this application no longer depended on limited access to a single kiosk (different-place, different-time communication, instead of same-place, different-time communication). Our tree-based layout was a casualty of the limits of HTML and was replaced by the indented outline-style interface. The opinion area and discussion area remained.

Building a Theory of Socially Relevant Representations

How did we use this design-based research to investigate theory? While there is debate about what precisely are the characteristics of design-based research, I believe our example to be relatively prototypical. Our work involved a theory-driven, iterative design of an artifact and associated activities that constituted a learning environment over a long period of time (eight years, to be exact). We tested our intervention in a variety of learning contexts; each iteration was implemented and evaluated in some authentic learning setting. Our design work was in some cases connected to intuitive or informal knowledge, but more often was the result of embedded investigations over the course of the development trajectory. We altered our intervention on a daily basis if needed to support its success in context, but we also created planned comparisons between successive versions of the intervention, or between versions administered simultaneously to different populations in a similar or the same setting. Our data collection was principled, but wide ranging; we collected some data to help orient us to the phenomena at hand, but also collected targeted data related to the planned comparisons (experiments) embedded in the work, and gathered still other data to help elaborate or explore poorly understood aspects of the phenomena (rich description). We also used a variety of informal data sources, such as our own experiences in the context as participant observers or the input of expert designers, and used these to help guide not only the design, but also the more formal research activities such as treatment design and data collection. Constructing theories, design hypotheses, and sometimes more fragile understandings of how our treatments played out in context were the primary goals. Falsification was an important part of our work; in some cases, we were able to falsify null hypotheses, and in many others, we were able to falsify incomplete or incorrect understandings of the learning taking place.

Through our design work, we stumbled on an area that appeared to be central to our success—how students construed the social space they were entering when they participated in online discussion. Intuitively, we felt that there was a great deal of social connectedness and motivation wrapped up in our tool, in part due to the nature of the representations in the interface. We began to develop a theory of how social cues, such as the face icons and our semantic labels, might be influencing student cognition and might facilitate sensemaking and learning (Hoadley, 1998; Hoadley & Hsi, 1996; Hoadley, Hsi, & Berman, 1995b; Hsi & Hoadley, 1994). As a design strategy, we began explicitly manipulating and studying various social representations in the interface, such as identity (as conveyed through the face icons) (Hsi, 1997; Hsi & Hoadley, 1997). We also began hypothesizing mechanisms by which social cues might aid learning.

One method we used to aid in development of this theory was to look longitudinally over our design trajectory. As soon as we began to suspect that social cues were facilitating participation and learning, we began to manipulate our design accordingly. In some cases, this took the form of following success; we tried embedding additional social cues in our *SpeakEasy* interventions, such as linking to descriptive personal homepages, adding short usernames to the comment icons, and moving some of what had been placed in seed comments into introductory videos of actors voicing those seed comments.

Embedded within our design-based research trajectory was a chance to run traditional treatment-control studies, in which some participants received one version of the intervention and others received another. We could sometimes compare an improved version against baseline data (one semester of students compared against another), but in addition we could randomly assign students to conditions, some of which were designed to gather information by introducing changes we thought might be worse, to test our budding theories. For instance, we compared students in discussions who were forced to make all comments anonymously with students who were forced to identify themselves on all comments.

*We were beaten to the punch by *Hypernews* by a few months.

More than simply analyzing the dependent variables in these cases, we collected rich descriptive data about how the students participated with the system and used these to further inform our theory. By trying out various representations, collecting data from not only participants but from the literature on interfaces, and iterating, we improved our understanding of how a particular treatment corresponded to a theoretical entity. Elsewhere (Hoadley, 2002) I describe how our notion of anonymity changed as a result of this kind of iteration—initially we saw anonymity as evidence of social inclusiveness because it improved participants' perceptions of social safety, but later we realized that social safety was independent of the use of the anonymity function and that in fact this feature threatened inclusivity.

Sometimes design-based research gave us a chance to refine the ways we operationalized our theory, helping to increase the alignment between our theoretical notions (in this case, "representations of social cues in interfaces") and how those notions were embodied in the research setting and their effects measured. Sandoval has termed this type of exploration the testing of "embodied hypotheses" (Sandoval, 2002, in press) We had a lot of exploring to do in terms of what constituted a more or less socially relevant representation. In one very promising early study, we compared the standard version of *SpeakEasy* that was designed to "feel like a conversation" with an interface that used similar screen layouts, but that was altered to feel more like posting to a database. We used visual icons that were not faces to represent contributors, and changed the discussion area from a discursive organization (semantic labels and a response-oriented thread structure) to a topical organization (labels such as "pro" and "con" and a conceptually oriented thread structure). Our results were somewhat surprising; students participated equivalently in both formats (same number of comments, same comment quality), but had different outcomes. On the positive side, more students changed their ideas based on the activity in the socially relevant condition, but frequently they changed their ideas for the worse! By doing *post hoc* analysis of the comments themselves, we were able to trace this back to some of the particular seed comments we provided. This led to continued refinement of our notion of mechanisms for socially relevant representations (SRRs) to support learning and also led to changes in the activity structure that were irrelevant to our ideas about how SRRs worked, but that were necessary (but not sufficient) for learning and conceptual progress.

The research trajectory culminated in a series of studies that suggested that SRRs can enhance learning outcomes, but indicated there are significant individual differences in how these representations are used. Through a combination of interviews, surveys related to social orientation, and learning and recall tasks, we were able to determine that some students (approximately half) use social cues in navigating *SpeakEasy*, that some (but not all) students encode and remember these cues in their understanding of the topic of discussion, and that on average providing students with social cues led to better learning outcomes in *SpeakEasy* discussions (Hoadley, 1999a, 1999b; Hoadley & Linn, 2000).

Theory Building and Testing

Our design-based research methods helped us build theory in four ways: induction, orientation, constraints, and manipulation.

Induction. Induction is perhaps the most obvious form of research, yet is often overlooked. We collected a great deal of data on the use of our tool in various contexts. While some have argued that over-collection of data may be seen as a weakness of design-based research (Dede, 2004), it also permits hypothesis generation from a large body of knowledge and is especially effective when deduction from known first principles is not possible. Additionally, because the design-based researcher has intimate knowledge of the research setting, the researcher can draw educated guesses about which explanations for the observed phenomena might be most parsimonious. It is difficult to apply "Occam's razor" from afar.

Orientation. Learning in context is a complex system, with multitudinous interacting factors. Which matter most for success? This is an important design question that poses challenges for research. By focusing on the design of the learning environment and the improvement of that design over time, the design-based research process is forced to converge quickly on what works through refinement and hill-climbing within a design space. The net result is to help orient the researcher quickly to those factors that are most design-relevant in a given context with a given set of tacit design assumptions.

Constraints. An infinite number of theories can be generated to explain any finite set of data. However, much as sampling may be used to test a model created with one subset of data by attempting prediction on another subset of the same data, design-based research allows theories to be falsified by systematic additional analysis of existing data. Comprehensive data collection in design-based research permits not only this type of model validation based on subsampling, but also allows additional post hoc analysis in which models, hypotheses, and in some cases theories can be put up for falsification by making predictions about data already collected and then examining that data. Since creation of rich, contextualized interventions is enormously expensive, and orientation to relevant

factors in these interventions requires intimacy with the research setting, this type of post hoc analysis and/or theory constraint through prior data can be invaluable for testing ideas in an authentic way.

Manipulation. Manipulation is the heart of experimentation. In traditional controlled laboratory experimentation, we manipulate the world in precisely controlled ways to test our theories' ability to predict the outcomes. But what can one do when theory incompletely predicts an outcome, or when variables cannot be controlled? Some would argue that inferencing must not take place in these circumstances, but Dewey would argue otherwise: "The conjunction of problematic and determinate characters in nature renders every existence, as well as every idea and human act, an experiment in fact, even though not in design. To be intelligently experimental is but to be conscious of this intersection of natural conditions so as to profit by it instead of being at its mercy" (Dewey, 1925).

The very nature of design (as opposed to problem-solving or deduction) is reasoning under uncertainty, in underconstrained problem spaces, where the outcomes of actions cannot be fully specified. In design-based research, we can take advantage of this type of reasoning, by incrementally increasing our understanding of a particular designed intervention in a particular context over time. We poke it, prod it, and continuously monitor the results. Much as calculus suggests approximating the change in a function's output by applying smaller and smaller changes to its input and taking the limit, we add incremental "deltas" to our interventions in design-based research and view the results. This provides not only a means to get to a particular outcome (i.e., formative evaluation), but also provides a way to systematically explore the design space through hill climbing. As the relationship between interventions and outputs becomes better understood in one context, it provides the opportunity to attempt generalization to other contexts.

Conclusion

Design-based research boils down to trying to understand the world by trying to change it. This article focuses on some of the theory-building aspects of one trajectory of design-based research. Certainly, there are many ways to test theories, and many more ways to build or propose them. Design-based research is only one way to do these. It is not recommended in situations where other, less demanding methods (such as good guesswork and a simple experiment) will do. However, DBR can be useful for creating and testing theories in situations, such as complex educational technology innovations, where little is fixed: the interventions, the theories [both what Reigeluth terms instructional-design theories (Reigeluth, 1999) and more general theories of psychology or human-machine interaction (Carroll & Rosson, 1992)], and the context might all be incompletely understood.

Often, the choice faced by a researcher is whether it is more valuable to do messy research on big, complicated questions using design-based research, or whether it is more valuable to perform tightly controlled studies while limiting oneself to questions and interventions that can be tightly controlled. Or, put another way, "The contingency of artificial phenomena has always created doubts as to whether they fall properly within the compass of science. Sometimes these doubts are directed at the...difficulty of disentangling prescription from description. This seems to me not to be the real difficulty. The genuine problem is to show how empirical propositions can be made at all about systems that, given different circumstances, might be quite other than they are" (Simon, 1969). Design-based research can be one way to build theoretical, empirical propositions about learning with technology. □

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