

of a four-year longitudinal study using design-based research within a classroom as a living laboratory. Her group is using DBR to evaluate and evolve a pedagogical approach called "learning science by design" by keeping several variables constant (such as the teacher, pedagogy, and students) while varying key aspects, such as collaborative arrangements.

Ken Hay and his colleagues describe how DBR has aided the evolution of a particular learning tool within a larger suite of studies about the educational potential of virtual reality. They delineate how DBR aided with the refinement of the tool, pedagogical theory, curriculum theory, and research methods.

Chris Hoadley portrays how, through two stages of tool development and evaluation, DBR has enabled the evolution and refinement of a theory about socially relevant representations. He describes the ways in which DBR is a powerful method for testing theories about issues that really matter in real-world contexts.

Tom Reeves concludes with a synthesis of how all these articles are interrelated and complementary in their approaches to DBR.

Overall, each of the articles provides a different perspective on the "elephant" of DBR. I hope you will find these ideas and methods intriguing, worthy of putting DBR in an important place in the pantheon of educational scholarship. □

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Resuscitating Research in Educational Technology: Using Game-Based Learning Research as a Lens for Looking at Design-Based Research

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Educational technology research has been criticized for insufficient rigor and irrelevance. Design-based research is a method that offers tangible examples of powerful learning, better ties between theory and practice, and acknowledging learning in context. This article offers two examples of design-based research programs around game-based learning: One where researchers want to investigate a form of game-based learning that doesn't exist, and another where researchers want to develop better instructional theory through the investigation of learning programs with teachers. I argue that design-based research, although still presently under-specified and conceptualized, provides useful models for taking innovations from initial conception to implementation.

Design-Based Research

If educational research has a bad reputation (Kaestle, 1993), then educational technology research has a reputation as bad, or worse (Gordon & Zemke, 2000; Reeves, 1995, 2000). The criticisms of educational technology research are fairly well known: Trivial

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research, poor ties to existing research or theory, inappropriate application of methods, and findings that fail to inform practice, to name a few. Over the past decade, a number of learning scientists (and increasingly, educational technologists) have taken up *design-based research* as a methodology that addresses many of these issues. As is true for most labels, there are as many different definitions of design-based research as there are practitioners, but most coalesce around some shared assumptions*:

- (1) *There is a value in demonstrating powerful learning environments.* Education is a "design" science, so there is value in creating powerful learning environments and understanding how they work. This research can (potentially) result in both well-designed interventions (materials, artifacts, and software) and more robust pedagogical theory (DBRC, 2003).
- (2) *We need better ties between theory and practice.* Research (at least some of it) should address questions of genuine interest to (at least some) educators. These findings should also be presented in a way that is useful to practitioners (Reeves, 2000).
- (3) *Learning is complex and inherently contextual.* As most any teacher would tell you, teaching can be very complex. No two classes are alike. Methods that succeed with one class might fail with the next. From research, we know that the number of interacting "variables" present at any given moment are astounding: Race, gender, class, parents' socio-economic status, previous knowledge, self-efficacy toward a technology, self-efficacy in a subject area, and cognitive learning styles—all may or may not be at play in a learning situation. Historically, educational technology research has tried to control and minimize such factors, frequently resulting in non-significant differences or research results of minimal impact. Design-based approaches try to build educational innovations and theories that, rather than minimizing, *account for* how and when these factors overlap (Barab & Squire, 2004).

Of course, the idea of designing and understanding powerful learning environments is not entirely new, as the roots of these ideas go back at least as far as Dewey (1938) and his laboratory school.

What I will argue here is not that design-based research approaches are particularly new, but rather,

*For the purposes of this article, I will group together design experiments (Brown, 1992), developmental research (Reeves, 1995), and formative evaluation of instructional theories (Reigeluth & Frick, 1999) under the more general category of design-based research.

that their pragmatic approach to research can reframe some tired debates in educational technology research. In this article I draw from my own and my colleagues' research on game-based learning environments to argue that design-based research provides a useful framework for developing technology-enhanced learning environments and better pedagogical theory. Design-based research offers new ways for thinking about mixing research methods, dealing with complexity in learning environments, and accounting for the role of the researcher in educational technology research. For design-based research to be taken seriously, however, we need to do a better job of treating design experiments as learning opportunities rather than "pet projects," and we need better mechanisms for sharing data, learning from one another's work, and reporting failures.

Case 1: Designing Learning Technologies When What You Want to Study Doesn't Exist. Many turn to design-based research because they want to study a phenomena that does not yet exist. My own interest is in studying educational computer and video games. In brief, my research is guided by the observation that interactive digital entertainment technologies (or games) are a powerful, untapped medium for learning (Gee, 2003; Squire, 2002). Games are the industry standard in terms of designing for engagement, interactivity, immersion, and collaboration (Malone, 1981; Prensky, 2001). In short, if e-learning has developed a reputation for being "boring and mindless," games have developed a reputation for being engaging and challenging (Aldrich, 2003; Gee, 2004; Squire, in press a). Yet, games designed specifically for learning that are on par with entertainment games do not yet (and may never) really exist. Thus, in order to investigate the plausibility of "educational video games," we needed to understand not only the pedagogical potentials of the medium but also the factors driving or inhibiting their adoption, their effectiveness with different populations (particularly girls vs. boys), and the kinds of classroom activities needed to support learning through game play. Even if these results do not yield support for the effectiveness of games in schools, they might yield theoretical insights about motivation, the adoption of technologies, or the social organization of schooling (Squire, in press b).

These varied research goals required different research techniques at different stages in the inquiry. Early on, we drew heavily from Humanities research paradigms, particularly Kuleshov's "thought experiments" in early Soviet cinema, where he taught students to make films in the absence of expensive film stock through conceptualizing, blocking, and storyboarding (Holland, Jenkins, & Squire, 2003). We next designed conceptual prototypes of next-generation

educational games that would address questions in both education and game theory, pointing towards directions still largely unexplored by the mainstream games industry (such as using multiple plot structures to build diverse audiences; Tulloch & Jenkins, 1995). Borrowing techniques from market research (e.g., Laurel, 2003), we then shared these prototypes with students, teachers, and game designers to better understand how different constituency groups would react to educational games (Games-to-Teach Team, 2003).

Next, we built a prototype of our first game, *Supercharged!* (see Figure 1). Using rapid prototyping techniques, we experimented with different game play styles, built different interfaces, and modified specific game rules. We tested these prototypes with roughly two dozen players, yielding practical results (i.e., which controls were easiest to use) and more theoretical results (i.e., many game genres were confusing to most players). This latter finding led us to the important finding that few game genres span across broad user bases, so in order to appeal to a broad audience, we needed to build on familiar genre conventions, such as "maze" games.

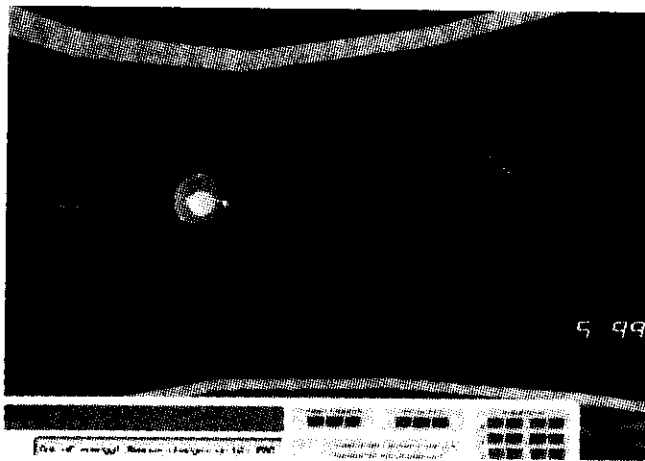


Figure 1. Screenshot from *Supercharged!*

After we settled on a usable interface, we shared the game with university and high school students as well as college professors. Using think-aloud protocols, we wanted to examine their thinking during game play. In doing so, we uncovered a surprising finding: Even MIT students held on to misconceptions about basic electrostatic concepts (in particular the strength of electrostatic forces over distances). Students repeatedly made errors in the game based on these beliefs, so we created a series of game levels that would challenge

these misconceptions (described more fully in Holland *et al.*, 2003). By the end of our user testing, we saw some conceptual changes in controlled settings and were ready to take the game "on the road."

We next took the game into one high school and three middle school classes using a curriculum designed in conjunction with teachers. We used a variety of research techniques, including qualitative methods (field notes, videotaping classroom interactions, clinical interviews) and quantitative methods (pre-post tests). The qualitative data led to two conclusions. First, students were more concerned with game design issues than the quality of graphics. Not one student complained about the game's admittedly primitive 3D graphics, but several commented about the game's controls or game mechanics. These observations lend evidence to (a) the "floor effect" theory, that students compare the quality of a game-based classroom experience to other curriculum rather than their experiences at home with computer games; and (b) a theory in game studies that users do not tolerate poor control systems. Second, we found that some girls refused to play the game, but those who did, on average, played longer than the boys. These mixed findings are preliminary evidence that girls *can* become engaged by educational games, but that there are barriers (at this age) in first picking up the controllers.

We also wanted to see how learning through a game based unit compared to an inquiry-based method, so we compared game-based middle school classes to control-group classes using an inquiry-based curriculum. In addition to pre- and post-tests for each group, we interviewed 25–30 students for conceptual understandings. We found that on pre- and post-tests students in the games condition performed roughly 20% better than those in the control group, with girls reaching higher gains in the experimental condition than boys (Barnett, Squire, Higgenbotham, & Grant, 2004). These results were encouraging, but perhaps not surprising, given the close fit between the assessment instrument and the game levels. Despite the limitations of these convenience samples (Shaffer & Serlin, in press), these comparisons allowed us to identify broad patterns between groups, lending evidence that this game, in this context, was more effective than inquiry-based instruction for reaching these particular objectives.

We were more excited by pre- and post-interviews results. For some students, Physics knowledge was *functional* within the game space, whereas for most in the control group, students simply memorized it for the test. When asked *how* they knew that field lines depicted electrostatic forces, students in the game condition described how field lines illustrated electrostatic forces that helped them guide their ship, whereas control group respondents often said, "we saw a picture in the book." Dynamic interviewing

land techniques and qualitative methods deepened the analysis, allowing us to probe the quantitative findings more deeply. Whereas some researchers have argued that experimental techniques are required to make causal inferences, I would suggest that the opposite may be true; quantitative techniques, in this case, are helpful in identifying broad patterns, but qualitative techniques allow researchers to dig more deeply into the meanings of the data.

A strength of design-based research is its capacity to serve as one framework for combining and integrating research methods at different phases of research (Shaffer, Squire, Halverson, & Gee, in preparation; Ross & Morrison, 1996). I have given one (albeit sketchy) blueprint here. In this case, *humanistic inquiry* can be used to define a problem and propose solutions; *traditional laboratory methods* can be used to refine a problem and design; *naturalistic qualitative methods* can be used to observe unfolding activity and unintended consequences; *experimental methods* can be used to delineate differences in consequences between curricular designs; and *clinical interviewing assessment* techniques can be used to probe findings. This is just one such framework, and admittedly it needs further refinement. One can imagine the addition of other methods, especially methods of critical inquiry or randomized experiments. Regardless, perhaps design-based research can help the field transcend old methodological wars and instead consider what different methods can do to solve problems.

Case 2: Designing Better Instructional Theory Through Researching Context.

Not every design-based research project involves designing software or testing entirely new pedagogies. In most cases, we already have an idea of what to study, such as in exploring inquiry-based science or communities of practice for professional development (Barab & Squire, 2004; Krajcik *et al.*, 1998). In these cases, what marks design-based research as a unique enterprise is a *commitment to understanding learning and instruction in authentic contexts and improving a program through iterative experimentation*. Most design-based researchers want to study learning in rich contexts that can account for all the "messiness" that traditional laboratory studies seek to eliminate. As such, design-based research is a useful framework for educators studying learning in existing classrooms and who have the ability to tweak or improve these environments toward building a better theory of learning or instruction.

In my second example, I will consider a design experiment using the commercial computer game *Civilization III* in world history classrooms, which led to some new theoretical insights in motivation and game-based learning pedagogy. The first case study suggested how a relatively simple 3D game can be used to help teach Physics, but what happens when we bring a

commercial-quality computer game, with all of its complexity, into the classroom? Is such a game even more motivating, or does a game-based approach only appeal to certain learners? How do students interpret complex games as "texts"? Curiously, we do not have good answers to these questions. Despite the broad popularity of "edutainment" games such as *Sim City*, *Civilization III*, *Railroad Tycoon*, or *Roller Coaster Tycoon*, there has been little, if any, study of how they might be used for learning. Theorists pontificate about both the opportunities and dangers of using games such as *Sim City* in classrooms, but no one has really looked to see how students react to such a game (Starr, 1994; Turkle, 2003).* My dissertation research focused on what studying such a game could tell us about motivation, building game-based pedagogies, the nature of digital literacies, and the potential of games for learning more generally.



Figure 2. *Civilization III* on a realistic world map.

Over the past two years, I have been building curricula for using *Civilization III* in schools and after-school centers. *Civilization III* (see Figure 2) is a turn-based strategy game where players lead a civilization from 6000 B.C. to the present by securing natural resources, building cities, managing their civilization's resources, creating domestic agendas, and trading with other civilizations. Working with teachers, I designed a project-based curriculum where students would play *Civilization*, and use the game to answer questions

*A number of creative educators like Mike Lipinski (<http://www.fi.edu/fellows/fellow3/apr99/simcity2000/what.htm>) have begun studying this, but so far there is little empirical research on it.

about history. We hoped that playing the game would (a) give them a better sense of historical timescales; (b) introduce them to historical concepts; (c) give them a better background knowledge of geographical facts; (d) help them see links across economics, politics, geography, and history; and (e) inspire historical inquiry. The teachers hoped that these poor, minority-group high school students, most of whom "hated history" and "avoided it like the plague," could at least find Egypt on a map and maybe position it in historical contexts.

We imagined that playing *Civilization III* would be motivating, but the opposite was true. The first class periods were marked by chaos, disorganization, and students' struggles to understand basic game concepts. Most students did not understand the idea of playing a game at school, and asked, "Why are we playing?" or "What is the point of this?" Although all of these students were gamers, few were familiar with strategy games, and none had played turn-based strategy games. The strongest students in the class wanted to see how playing a game would improve their chances at getting into college. The weaker students and console gamers did not really understand the basic interface.

On the fourth day, I re-introduced the idea of "replaying history," using the game to explore hypothetical history. Until this point, students had treated the game as an interactive narrative with pre-defined beginnings and endings, but class morale shifted as some students finally saw how they could *change* history within the game. Soon, *Civilization III* captivated several students, each for unique reasons, ranging from building an empire, to exploring the map, to building cities. Dan, for example wanted to "rewrite history" by playing as a Native American tribe that could fend off European colonists and retain Native American lands. Another student wanted to play as the Japanese and avenge years of Chinese oppression.

These experiences caused me to reorient my theory of motivation to include students' goals, identities, and the broader social context. According to the existing research literature, games are motivating to students through challenge, fantasy, curiosity, and control, as the existing research literature would have predicted (Cordova & Lepper, 1996; Malone, 1981). In this case, game play was thoroughly wrapped up with students' identities. *Civilization III* engaged those players affiliated with gaming culture and affronted those students who believed that games were a waste of time. Students whose political beliefs aligned with the game's to enable "replaying history" were also engaged. Rather than treating motivating as a static "property" of a game or "motivation" as the property of a person, I started to view the problem as "when does an alignment emerge among teachers' and students' goals, the affordances of the game, and the institutional constraints of schooling?" One can imagine how a summer camp

filled with students who elected to play games and did not bring the expectations of schooling into the experience might react differently.

These findings about motivation in game-based learning environments were one area of theoretical insight; a second was in building an instructional theory of game-based learning. The unit for which it was originally designed featured students playing the game in order to build a better framework for understanding world history. However, we quickly learned that the game was so difficult that simply learning to play it successfully would drive most of the classroom activity. By the third week, we completely abandoned the idea of having students build culminating projects about their games, realizing that building a civilization that could survive for more than a few centuries was not only difficult, but stressful.

Watching students play the game helped us develop a new framework for game-based learning. As we observed students playing the game, we noticed that most started to uncover the geographic/material basis of the game. Most students realized that civilizations in river valleys grew much more quickly than those in woodlands, as they compared the progress of the Egyptians and the Iroquois across games. One student even played two games simultaneously so that he could compare them, much as a scientist might compare scientific models. Second, students identified trade-offs between playing in the old world where they had access to global trade networks, but also had to fend off competing civilizations, with the new world where there was lower population density, but no access to global trade. Both of these discoveries hinged on students learning the underlying properties of the game as a geographical/materialist simulation of history.

Seeing what students were learning from the game suggested that its pedagogical power may be in presenting a coherent theory of world history. At the end of the unit, students each wrote on Post-it notes what they learned from the game, and we compiled them into a presentation. As one student (Tony) described,

Well, in some ways, (it's that) they (history, geography, and politics) are all related to each other...well, money is the key...money is the root to everything. With money you can save yourself from war, and that also means that politics...with money, that ties everything together.

Tony's note observes that *Civilization* connects history, geography, and politics, but that underlying the game is a *materialist* bias. In post-interviews, he revised this theory to emphasize the importance of starting location (geography) on the growth of civilizations. *Civilization III* is a materialist geographical representation of history, and the students who stuck with the game interpreted this thesis.

Based on this experience, I am currently developing a different instructional theory for using *Civilization III* in similar classrooms that treats the game more as an historical text to be interpreted and critiqued. Rather than treating the game as an inroad to studying history, I now approach the game as a text making an historical argument about how civilizations wax and wane over broad time scales. *Civilization* argues that it is not culture or "great men" that affect history on these time scales; it is largely being at the right place at the right time—namely access to natural resources, both food "packages" and raw materials, and global trade networks, much as does Jared Diamond's (1999) Pulitzer Prize winning history *Guns, Germs, and Steel*. Thus, the instructional theory is changing to include (a) more focus on understanding the assumptions and properties of *Civilization III* as a text, and (b) more opportunities to apply these understandings in interpreting historical scenarios.

This example draws our attention the role of the researcher in design-based research. In traditional social science research paradigms, researchers stay as objectively removed from the experiment as possible. Explicitly drawing from the biological sciences, we don't want to "taint" the research environment, much as one does not want to soil a Petri dish. In design-based research, researchers tend to do *just the opposite*. They tinker with both a design (which can be software, such as *Supercharged!*, or an instructional design, such as the *Civilization III* unit) and theory to better match their observations with what they had expected to see.

This approach may seem unscientific, but I argue that it is more useful than research paradigms which break down classrooms into isolatable variables. In educational environments, we know that there are at least *dozens* of interacting variables operating at any given time. In the *Civilization III* case, we saw that students' attitudes toward games, experience with technology, gender, attitudes toward school, perceived requirements to get into college, and so on, all played a role in shaping activity. In this case, simply measuring for a few variables and ironing out all extraneous variables would miss some of the most important parts of the story, from the perspective of generating better instructional programs and theory.

What design-based researchers try to do is enter an instructional situation, with all of its complexity, and experiment until they have "working" prototypes and more robust theory (Cobb *et al.*, 2001). From this perspective, we can think of every little researcher action as an experiment—changing the environment and observing the consequences. The good researcher makes these changes in a way that is informed by theory and will hopefully yield better theoretical insights. Within my own work with *Civilization*, I began with motivation theory and an instructional

theory informed by project-based learning, but then made modifications as necessary. The key to good research from this perspective is in clearly articulating learning goals, thoughtfully implementing and tracking changes, and then diligently rethinking experiences so as to generate more powerful theories to guide future work.

There are, of course, times when it is useful to draw comparisons (see the *Supercharged!* example), and classic experimental methods are one way that we can draw such comparisons (Shaffer & Kalish, in press). Whereas traditional experiments are based on an objectivist framework of rigorous sampling, methodical administration of treatments, and warranted claims of generalizability, design-based experiments, when they do experimental comparisons, have a more pragmatic orientation designed to make smaller claims (Cobb *et al.*, 2001). As in the case of *Supercharged!*, experimental comparisons are more often run in order to make a specific argument about a specific set of instances. Because they are committed to working in the complexity of "real world" classrooms and other learning environments, design-based researchers can rarely exercise the control over sampling procedures or the implementation of the study that traditional psychometrics demands. Within my own work, at least, such comparisons are made not to uncover timeless "variables," but rather, to make an argument toward building more powerful theory, a stance more informed by pragmatic epistemology than traditional "objectivist" or "subjectivist" epistemologies (Peirce, 1877/1986).

The Future of Design Based Research

In this article, I have argued that design-based research is a powerful paradigm for conducting educational technology research. Three of the commitments driving design-based researchers (demonstration of powerful learning environments, better ties between theory and practice, and studying learning in complex situations) respond to many of the critiques of instructional technology research. Design-based research provides a paradigm for both inventing new learning technologies (see Case One) and building better instructional theory, two research activities central to educational technology research.

Design-based research still faces challenges. In the interest of honoring the complexity of learning environments, many design-based researchers shy away from articulating what variables are at work in a learning context, or making comparisons across different learning environments. Unfortunately, design-based researchers have been largely averse to reporting failures, so we have not done a good job of learning from one another's failures. There are several reasons for this—ranging from the nature of grant funding, to tenure demands, to what journals report and accept, to

matters of personal pride. Better transparency within research projects is one solution; another is to take *less* a stance of advocacy for particular research and more one of scholars investigating questions of genuine doubt.

A final issue that design-based researchers face is the nature of responsibility toward the broad educational system. In our drive to work in "authentic" settings, we struggle with whether to accommodate to the "realities" of schooling, or to advocate systemic changes necessary for innovations to thrive (see Dede, 2004). This feature of design-based research may be valuable in helping to see limitations in contemporary systems (Squire, in press b). Educational technologists occupy only one seat at the table of designing our educational systems, but if we simply acquiesce to the status quo, we risk perpetuating an educational system that is already teetering on irrelevance. □

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