Games and Simulations in Informal Science Education

Kurt Squire, University of Wisconsin-Madison

Wisconsin Institutes for Discovery

Nathan Patterson, Morgridge Institute for Discovery

This white paper seeks to outline the possibilities and challenges that games and simulations pose for informal science education. Three crucial opportunities (and related) challenges shape the field:

1) Informal science educators are largely free to pursue a variety of educational goals, from increasing ethnic diversity among scientists to increasing interest in science, technology, engineering, and mathematics careers, to increasing scientific citizenship among the general populace. Further complicating the matter, informal science educators operate in environments ranging from unstructured settings such as homes to highly structured workshops. This diversity in goals and context frees educational game designers to create experiences that appeal to personalized, students' interests or span home, school, or after school contexts (and indeed *requires* them to do so). However, such diversity of goals, contexts, and methods for reaching those goals makes a fragmented field.
2) Much of research, theory, and practical wisdom in informal science education occurs outside the traditional domains of science education. Some of the most complex forms of scientific thinking occurs in commercial entertainment games with no overt educational goals at all. Further, edutainment games have far greater budgets, scope, and polish than most educational games and simulations (frequently

developed in research contexts). However, they may also lack coherent models of educational game play, privileging marketing or commercial goals over some educational values.

3) Research methods appropriate to informal science education contexts are needed. Informal science educators, tasked with competing with *all* of the other potential "out-of-school interests" have been deeply concerned with methods than enable them to improve designs particularly in how to create quality materials (i.e. process goals), build and sustain learner, interest and engagement, support learners in forming identities affiliated with science, and in creating lifelong interest in the field. There is a general desire to treat design seriously as its own field, rather than as a "natural extension" of learning theory. The diversity of informal science educators' goals, methods, and contexts puts it outside the purview of much of the contemporary discourse in educational research (see National Research Council, 2002). The key features of informal science education (interest-driven learning, voluntary participation, divergent learning outcomes, connections across contexts rather than isolating variables) run counter to the underlying logic of many predominant research designs (such as randomized controlled trials). Yet, research methods are needed that produce credible evidence for learning through experiences with games and simulations in informal contexts.

The paper begins with a brief introduction of simulations and games in informal science education, seeking to connect the relatively disparate enterprises of research, theory, and practical wisdom from education and entertainment games across a variety of contexts. It provides a short history that frames the paper and attempts to clarify ambiguities between games and simulations. Next, it examines the research and theory on learning in *structured* informal learning environments (workshops, after school programs, some museum workshops) and the paper provides a framework for contrasting these structured informal learning environments with more formalized learning environments such as school. Next, it reviews research on relatively *unstructured* learning environments (such as home or online experiences). The paper then turns its focus specifically to research on *learning* across these contexts. Finally, it concludes by briefly offering some thoughts on the opportunities and challenges for informal science education with games.

Recently, there has been a re-awakened interest among educators in video games and their associated technologies for education. A wave of science-based learning games, including *Whyville, WolfQuest, Fold.it, Resilient Planet, Nobel Prize games, River City, Evolution, Pontifex, Mind Rover, Immune Attack, MeChem, Sharkrunners, Quest Atlantis, Supercharged, Mad City Mystery* and *Star Logo NG* are all designed to support science learning in formal or informal contexts. Some of these come from academia, but many were also created in entertainment or commercial contexts and have not been researched. A challenge in conceptualizing the field is how to balance the need for theory-driven research with research responsive to the innovations occurring outside of academic contexts.

Although dozens of games and simulations have been developed for informal science education, there is still a paucity of research on them. The wave of educational games released in the 1980s and early 1990s largely ran counter to prevailing educational concerns, and thus were not researched extensively. The most robust program of research around this era of games was the Fifth Dimension Project (Brown & Cole, 2002; Cole & The Distributed Learning Consortium, 2006; Ito, 2003). The Fifth Dimension is a role-playing meta-game based around existing commercial off the shelf computer games. Ito (2003) describes the games of this era as falling into three genres: Edutainment, entertainment, and authoring games. Ito writes,

> The genre of "edutainment" was founded by progressive educational reformers pursuing equity in learning, but has gradually been overtaken by more competitive and achievement idioms in its commercialization. The genre of "entertainment" is dominated by visual culture, produced by entertainment industries in alliance with children's peer culture. The genre of "authoring" grows out of a constructivist approach to learning and hacker subcultures, and becomes a tool for children to create their own virtual worlds and challenge the authority of adults. (Ito, 2003, p. iv).

Fifth Dimension research emphasizes the centrality of *context* in determining how participants appropriated such software. Different encompassing institutions (from libraries to schools) implant their own participant structures upon the software influencing its appropriation. Children's own voices and goals co-constitute how the games are (or are not) appropriated as tools as well, as they may place their own cultural framings of video games, toys, or other cultural categories upon games (Ito, 2003). Papert's (1987) research on LOGO makes similar claims, reminding educators that it is impossible to reach "LOGO," but rather, one always researches LOGO implemented for particular reasons in particular contexts.

Ito describes how the edutainment and educational games of this generation largely drifted away from the educational values of their original designers. Indeed educators have criticized much of this generation of software for its failure to integrate content and game play, poor production values, and generally "dumbing down" for educational audiences (Jenkins & Squire, 2004; Holland, Squire Jenkins, 2004; Papert 1998; Ito, 2003; Squire, 2006). A new generation of games built on learning sciences principles and contemporary developments in the commercial video games industry seeks to re-insert such complex problem solving back into games. Indeed, a host of new games – many of which are actually quite good by most accounts – now suggest the potential for creating immersive learning experiences in which core game play is tied to academic practices in science (Gee, 2003; 2005; 2007; Klopfer, 2008; Shaffer, 2006; Squire, 2006).

What are Games and Simulations?

Before further going further, it's worth considering what is meant by games and simulations and giving bounds to the scope of the inquiry. The differences in textbook definitions between games and simulations are pretty simple. Games are sets of rules that are temporarily adopted for the purposes of entertainment. While playing *Monopoly* we all agree to assign a value to take turns rolling dice and moving pieces, trading *Monopoly* money, and so on. *Monopoly* is also instructive in that it is a blend of written and "house" rules. Most people write their own rules to achieve various ends, such as speeding play (see Salen & Zimmerman, 2003).

Simulations, in contrast, are generally defined as representing one symbol system through another. This definition is simple enough when it comes to weather or health care simulations, but what about a case like *Monopoly*? *Monopoly* is a game in that it has rules that players adhere to for enjoyment, but also a simulation in that it could be regarded as taking the real estate market and remediating by a set of materials (dice, squares, and player symbols). Critics might note that *Monopoly* doesn't seem like a particularly *good* real estate simulation, and in fact they might be right, depending on what *Monopoly* was purported to be a simulation *of* and for what *purpose*. If someone wanted to predict the next 12 months of real estate values in Southern California following the sub-prime crash, *Monopoly* wouldn't be especially useful. On the other hand, if you wanted to show an eight-year-old the basic idea of how monopolies stifle competition, you could imagine how that might work.

The more consequential difference between games and simulations for many is who *developed* them (i.e. do the developers come from the game community or the simulation community) and then for what purposes they are *deployed*, rather than being static properties of the media themselves (see Sawyer, 2006; Squire, 2006). Many simulation developers come from military, health, and science backgrounds, and place a premium on representing systems with *accuracy* (sometimes for legal reasons), beginning with a realistic simulation and then scaling backwards. Game designers, in contrast tend to focus on the player's *experience* of the media, and "cheat", by intentionally reducing model accuracy, in order to achieve these goals. Prensky (2000) describes how the military simulation developers were "blown away" when they played the entertainment versions of the military flight simulators. The entertainment developers "cut corners" in aspects of the simulation that players never experience, enabling them to gain much better performance in areas that they do experience. Observers of both industries have noted how these differences in orientations to development have led to different development tools, programming practices, and ultimately products (Prensky, 2000; Sawyer, 2006).

The research that *does* exist on contemporary games in informal science education settings spans completely unstructured contexts (such as homes) and semi-constrained contexts (such as after school clubs or museum workshops). The unique concerns of informal science educators have not been properly addressed, perhaps because most games-based research is produced by educators working in formal classroom education settings. The needs of informal science educators (such as developing interest in science or building affiliations with science identities) have often taken a backseat to academic concerns. Further, the unique opportunities for informal science institutions to pursue local place-based education or scientific citizenship through games have not been explored extensively. As a result, this review draws upon edutainment, education, and authorship games where appropriate in terms of understanding the challenges and opportunities to science educators.

Simulations and Games in Science Education. Science educators offer a way out of the dilemma between "games and simulations" by distinguishing between *idea* and *predictive* simulations (Edmonds & Hales, n.d.). The difference is straightforward: Is the simulation designed to predict the future vs. is it designed to illustrate key relationships? Predictive simulations are most often used for *planning* – either in social policy (what is the fate of social security under current conditions?) or the natural sciences, (such as weather prediction, e.g. will it rain tomorrow?). In contrast, educators (and many scientists) are generally looking for insights into a particular idea. Instructional designers make similar distinctions between *high fidelity* and *low fidelity* simulations and maintain that low fidelity

> *Resilient Planet* is a scientific role playing game developed by Filament Games for classroom use, but it is also a free download available via the National Geographic Website. One can easily imagine how it might be tied to a museum installation or issue of local importance.
>
> In *Resilient Planet*, players are scientists investigating a decrease in monk seals in a marine reserve in Northwest Hawaii. They drive an underwater vehicle tracking, photographing, and counting sharks. They also tag seals, pump sharks' stomachs to investigate their diets, and place cameras on seals to "observe the world as a seal" might.
>
> Back at the lab, players use their data to construct arguments about scientific phenomena. Through series of arguments, they expand their notions of scientific phenomenon, argumentation, and the nature of scientific inquiry.
>
> As an example of the issues in predictive vs. idea simulations, *Resilient Planet* originally included a "realistic" ecology of predators and prey in which the species reacted to the player and one another in realistic ways. After weeks of experimentation, the game designers deduced that they could create an ecosystem that functioned "good enough," by stripping out the simulation and simply scripting events (White, 2006). Stripping out the simulated components enabled them to focus instead on the player *experience*.

simulations are often most desirable for learning. High fidelity simulations are typically computationally expensive and potentially confusing to newcomers.

As such, simulations used for teaching – idea simulations -- have an entirely different set of “success criteria”. Idea simulations are often valued for their elegance and explanatory power with a relatively few number of variables (see Carpenter, et al. 2008). For example, the classic Lotka–Volterra equations (which are the basis for many predator prey models) show how a system with too many predators eventually results in a reduction in prey. When too many prey die, then predators begin dying as well. The reduction in predators then creates, in turn, an overabundance of prey. Then, the prey dies off as it overfeeds, and the predator population to rebound. These fluctuations continue, and Lotka-Volterra shows how such fluctuations result in spikes in both predator and prey populations, enabling ecologists to make sense of their observations in the world.

Modeling and Gaming Social Practices. When viewed as social practices, there are key differences in modeling (or model building) and gaming as modes of *inquiry*. Modeling involves the recursive process of observing phenomenon and building representations to illustrate those core ideas (also called abductive inquiry, see Peirce 1877/1986). Models such as Lotka-Volterra are *constructed* by scientists. Scientists engage in cycles of data collection, model building, and model testing. In contrast, *games* are generally constructed by *experts* trying to communicate ideas to novices. Educational games seek to teach the player the model’s rules and emergent properties through playing them (Gee, 2003; Squire, 2005). However, this mode of learning by which players learn is also *abductive*, in that they hold models about how the world works, and then are forced to amend those understandings as they encounter new experiences of them.

Although these two processes are distinct enough to keep separate, paradigms of game-based learning often deliberately try to *blur* them. Games such as *GameStar Mechanic*, or game design curricula in which students design local games, seek to create series of tight, integrated loops of playing and designing games (Games, 2008; Mathews & Wagler, 2009). This learning-through-gaming model that integrates game *play* and *creation* seeks to capitalize on the agency provided by game authoring packages, while also *guiding* the learner in a way most open-ended approaches do not. As such, it seeks to respond to recent critiques of constructivist and inquiry-based pedagogical approaches that note the difficulties educators have in immersing students in complex, open-ended tasks *before* they develop robust understandings in domains (Kirschner, Sweller, & Clark, 1996).

Research results on these more recursive play- design styles of games is still emerging and evidence is needed before we will know to what extent it addresses this dilemma. This said, games offer one model for teaching learners the requisite knowledge, skills, and attitudes in a manner that prepares them for more open-ended tasks (Shaffer & Gee, 2005). The learning "cycle" in games involves recursive experiences of developing goals, observing phenomena, hypothesizing how they might act within the system to achieve those goals, observing the results, and then repeating (Aldrich, 2003; Ito, 2003 Salen & Zimmerman, 2002; Squire, 2006). Studies of *Sims* and *Civilization* players has shown that as the players learn the rules of the system, they can use editing tools to change those underlying rules to explore ideas or match their play style (Squire, 2008; Hayes & Gee, forthcoming). Indeed, as they become literate with game creation tools, they can use them to create their own modifications or indeed their own games (Games, 2008; Hayes & Gee, forthcoming, Squire, 2007).

Structured Informal Learning Environments

Informal science education contexts are different, unique, (particularly for those most familiar with more the more formalized, regulated nature of schooling) in that they are free to operate in widely diverse contexts. Whereas schools must respond to a variety of local and national political needs, pressures, and concerns, informal science educators have significant freedom in how they pursue goals germane to institutional interests. In designing local games for learning with informal science education partners, Squire, Wagler, Mathews et al. (2007) found educational goals, ranging from instilling a sense of civic ownership over local lakes, to fostering environmental ethics. Common goals of science educators range from increasing the diversity in science to promoting national science literacy (Miller, 1998; NAS, 2009). There are many factors known to increase such interest in science, including curiosity in topics (such as dinosaurs), to hobbies (such as radios, model airplanes, or video gaming), to experiences of natural places (such as a lake), to relationships with loved ones (Azevedo, 2006; Crowley & Jacobs, 2002; Feynman, 1985; Horwitz, 1996). Building games that leverage such ideas and mechanics is a natural route for designers of games in informal settings to pursue.

Sorting out the needs of organizations that span from local ecology groups to national associations of scientists can be difficult, but the National Research Council's (2009) report *Learning Science in Informal Environments* makes a strong case for six key facets of informal science education (see Table 1, below). These six facets apply to all science education contexts, but the report emphasizes the unique capacity informal science education has to: 1) increase interest in science and 2) encourage affiliation with science as an enterprise (building identities in science). Of course, any media--from books to lectures--may address these facets in any number of ways. Moreover, given the history of educational media research (see Clark, 2003), researching games in *conjunction* with other media is a better approach than comparing them or examining them in isolation. The NRC (2009) report emphasizes the importance of media as a *tool* for informal science education (used to achieve various goals) and as a*context* itself for studying science. Scientists have reported that experience with diverse media, ranging from science fiction novels to Legos to Logo, was instrumental in their decisions to pursue careers in science, and already there are reports of games driving students to computer science (Jenkins, 2004; Kafai et al. 2008).

The learning principles of games, as identified by Gee (2003) and others, suggest that games may be particularly well-suited for developing skills, knowledge, attitudes, and identities (see also Shaffer, 2006). To illustrate, consider how*Resilient Planet* (produced by National Geographic and Filament Games) embodies these facets.

Table 1. Facets of Informal Science Education and Ways Addressed in Resilient Planet

Facets of Informal Science Education	***Ways Addressed in Resilient Planet***
1. Experience excitement, interesting, and motivation to learn about natural and physical phenomena.	Resilient Planet leverages an intrinsically interesting aspects of science, the allure of underwater exploration
2. Generate, understand, and use concepts, explanations, arguments, models, and facts related to science.	Players construct arguments about the causes of various phenomena, such as the monk seal population reduction or the health of the ecosystem.
3. Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.	Players use cameras and vehicles to observe phenomena, and then compare the data they gather with that predicted by models.
4. Reflect on science as a way of knowing;	The game includes multiple types of

on scientific processes, concepts, and institutions; and on their own learning.	investigations enabling students to experience or compare different types of investigations.
5. Participate in scientific activities and practices using scientific tools and concepts.	Players are given access to authentic tools that they use to conduct procedures such as biodiversity surveys.
6. Affiliate with the enterprise of science, developing an identity as someone who knows about, uses, and contributes to science.	In order to appeal to Students' interests, players assume roles as one of four different types of scientists.

Games such as *Resilient Planet* suggest the great potential for using games in informal science education contexts. However, it, like many educational games was designed to be used in schools. As such, it is only a few hours long, is relatively linear, and by design eliminated some features (such as the chance to freely explore the world) that one might want in an educational game. One might imagine how a game designed for informal science would include more open-ended game play, more collaborative problems, and better ties outward from the game experience toward scientific communities of practice.

In fact, the research on informal science educational contexts emphasizes the unique different opportunities and constraints they face (NRC, 2009). Table 2, below, compares some of these key factors as they pertain to games. These comparisons along particular dimensions (such as how time is structured) are not intended to put informal settings "in response" to formal settings; informal settings maybe be every as important as formal settings in people's attitudes toward and experience of science (Barron, 2006; Crowley & Jacobs, 1992; NRC, 2009). Also, there are evident differences in how formal educational institutions are structured; Milwaukee, WI, alone has over 40 charter schools with a smorgasbord of constraints. However, although they cannot rely on compulsory attendance laws to require participation, informal science educators generally have more freedom in the topics they pursue, how they pursue them, and in the extent to which they need to serve all audiences. As a result, informal science educational institutions feature a diversity of programs, educational approaches, and learning outcomes.

Table 2. Comparison of Attributes of Informal and Formal Educational Settings

	Informal Settings	***Formal Settings***
Time Structure	Flexible	Rigid
Participation	Voluntary	Compulsory
Educational Goals	Emergent	Largely Defined
Age Grouping	Flexible	Largely Age Divided
Degree of Authenticity	Potentially High	Generally low
Uniformity of Outcomes	Little	High
Disciplinary Boundaries	Flexible	Fixed

As an example of these potential opportunities and pitfalls, DeVane, Durga, and Squire (2009a) describe their attempts to build systemic ecological-economic thinking among *Civilization* game players in an after school gaming club[1]. This curriculum aimed to tie together ecological, economic, and political concerns around a gaming series based on global sustainability (Brown, 1992; Diamond, 2005; Durga, forthcoming). Such a curriculum may be difficult to implement in schools that teach biology but not ecology, and that do not link either

[1] Civilization is an historical simulation game in which players lead a civilization over a time period managing its utilization of natural resources, cities' production, and strategic goals.

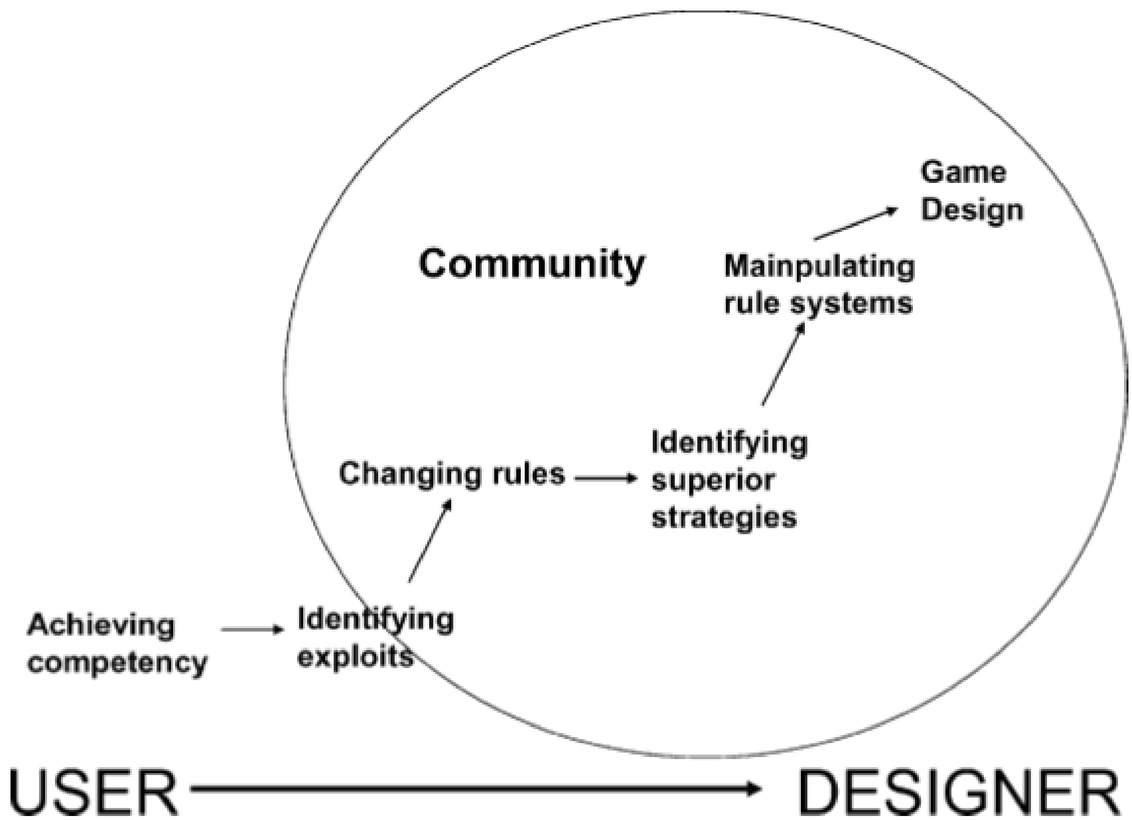
biology or ecology to economics on political science. DeVane et al. adapted *Civilization* to consider just these issues, particularly food shortages, agricultural policy, trade relations, and environmental concerns, reporting that participants developed a type of systemic thinking across geopolitical systems (see Durga, in press). Thus, pursuing this kind of educational goal may be much more feasible in informal settings.

At the same time, as a voluntary after-school option, participants chose it over playing basketball, cooking, or scouts. Moreover, many students resisted taking pre- or post- tests, particularly if they "smelled like school," making assessment difficult (a phenomenon also reported elsewhere in the literature--see Hayes & King, 2009; Steinkuehler & King, forthcoming). As a result, informal educators are much more concerned with building and sustaining student interest than most formal educators (NRC, 2009). In fact, informal science educators have the unique opportunity to pursue goals difficult in formalized settings.

Informal settings also enable opportunities for students to develop highly individualized interests and pursuits. Researchers investigating analogous programs in informal information technology settings find students developing deep interest and expertise in areas ranging from computer programming to historical modeling (Bruckman, Jensen, & DeBonte, 2002; Resnick, Rusk, & Cooke, 1998; Squire, 2008). These communities – like games culture in general – are built on a valuing of *expertise* (Squire, 2008b). One's background or credentialing matter less than one's ability to meet (and at times push the boundaries of) community norms. Figure 1 depicts the trajectory that game players undergo when becoming expert designers in Apolyton University, an online "college" of Civilization players. Those programs that involve lengthy participation (upwards of 100 hours) report players developing personalized and idiosyncratic skills that arise from an intersection among the participants' interests, the affordances of the game, and the pathways made available within the game playing community (Bruckman, Jensen, & DeBonte, 2002; DeVane, Durga, & Squire, 2009b; Resnick, Rusk, & Cooke, 1998).

Even in its most "structured" settings, the qualities of informal science education (participant-driven learning goals, divergent learning outcomes, flexible participation models, emphasis on developing interest) frequently run counter to the assumptions of many modern statistical methods (uniformity of learning outcomes, treatment fidelity, pre-specification of learning objectives, isolation of variables). As a result, educators working in informal settings have frequently preferred case studies or other methods that enable them to gain longitudinal data, understand the role of the participant in defining the learning experience, and examine how participants' identities are shaped beyond the learning experience. Certainly, experiments are still possible in such environments, but the importance of user *choice* in activities still creates challenges as it is (for example) difficult to administer a uniform task to multiple participants and expect meaningful results. One immediate direction researchers may pursue to understand patterns of behavior across broader numbers of participants is through methods such as non-parametric statistics. However, the underlying logical problems of "user-defined learning goals" or uniformity of treatment still need to be addressed.

Figure 1. Trajectories of Experience from User to Designer Among Gamers



"Unstructured" Informal Learning Environments[2]

In their ethnography of youth media producers, Ito and colleagues (2008) describe a similar process of "hanging out," "messing around," and "geeking out." This trajectory enables participants to enter media production cultures in non-threatening ways and provides multiple pathways toward developing expertise. Currently, educators are exploring potentials for designing informal learning spaces based on these principles, literally mapping out informal learning centers so that spaces (such as the downtown library in Chicago) are designed to promote these three activities (hanging out, messing around, and geeking out), and the fluid

[2] Unstructured is used here to denote the lack of an overriding social institution in structuring activity, although formal and informal rules and participant structures most certainly operate in these contexts.

crossing among them. This vision matches well with that of Squire (2006) and others, but as of yet, few educators have designed games for science built on this model of scientific literacy.

Design-based researchers have, however, begun to map out how to mesh forms of scientific thinking with game play, avoiding many of previous problems with science games that involved game play mechanics non-congruent, or even counter to the ways of thinking encouraged in science (Klopfer, 2008; Schaller, Goldman, Spickelmier, Allison-Bunnell, & Koepfler, n.d.; Squire & Jan, 2007). Because informal science educators must compete with all the other demands on youth (athletics, video games, television), they need to have sophisticated models of what constitutes academically engaging game play. Design, which is at times given a backseat to other forms of inquiry within educational research, is of *utmost* importance in a context in which a poorly designed artifact fails to attract any research subjects. With a new generation of educational games now released on the market (i.e. *Fold.it, Resilient Planet, WolfQuest*), opportunities exist for educators to study these designs and effects on players more formally.

Some of the most compelling research on the potential of games to support deep scientific thinking occurs completely outside the "designs" of educators. For example, Steinkuehler and Duncan (2008) examined participation in *World of Warcraft* (*WoW*) forums to examine what kinds of thinking take place in that context. Such forums are of particular interest to educators as they are where participants try to make sense of the game as a model; indeed games like *WoW* are large simulated models that players puzzle through. Steinkuehler and Duncan find that contrary to some expectations, the overwhelming activity in these forums was social knowledge construction (86%). This knowledge construction involved citing evidence, gathering evidence, and building original mathematical models to argue ideas. These models can be quite complex, involving several variables, coefficients, and modifiers.

The example of *WoW* suggests the potential for games to support large, multi-aged, diverse bodies of learners in pursuing complex pursuits. Although not every *WoW* forum participant necessarily “builds their own model” in an attempt to reverse engineer the game world, *WoW* forums functioned to model a type of discourse congruent with those of scientific argumentation. Steinkuehler and Duncan remind us that this sort of “reverse engineering” is a form of scientific inquiry (abductive reasoning, see Peirce, 1877/1936). However, because game worlds are intentionally programmed by designers and operate according to built-in mathematical rules there is a potential pitfall in that its rules are inherent simplifications of reality. At the same time, the practice of knowing by modeling (and then judging what works) is similar in games and in many sciences. ?

Further, this line of research reminds educators of the importance of looking beyond learning from any particular game to the study *how* learning occurs through gaming. Effective models of educational gaming may be created by designing compelling, multi-layered challenges and designing spaces for coordination and argumentation (see also *I Love Bees*, a game about distributed intelligence, McGonigal, 2007). Such spaces recruit players from multiple ability levels and diverse backgrounds, creating numerous opportunities for formal and informal apprenticeship.

Learning Findings in Games- and Simulations-Based Informal Learning Environments

These examples show some of the ways that scientific thinking is naturally supported by games and suggest how games may be particularly-well suited for informal learning environments. Scholars of different paradigms of education have begun to provide explanations for the learning potential of games and simulations in informal learning environments. These studies have considered participatory simulations, epistemic games, role playing games for citizenship, targeted games, and investigative role playing games in multiplayer virtual environments (Barab, Thomas, Dodge, et al., 2005; Colella, 2000; Nelson, Ketelhut, Clark, et al., 2007; Games-to-Teach Team, 2003; Klopfer, 2008; Klopfer, Yoon, & Perry, 2005; Shaffer, 2006; Squire, 2006; Squire, 2007). These explanations tend to emphasize the interactive nature of games, particularly how they function as worlds for player to inhabit and explore rather than traditional stories to be interpreted.[3] Design research on educational games emphasizes that games operate by an *experiential* logic; players are immersed in problem solving situations in which they adopt particular perspectives within simulated systems. Although there is relatively little evidence about the efficacy of games of this type (most notably *Immune Attack!, WolfQuest, Whyville*, and *Resilient Planet*), emerging research findings suggest there is great potential for the use of games for learning [in informal science education. Of particular interest in this regard are research findings about products such as *Whyville* or “augmented reality games for learning” (which are used at homes and in museums). Here we present findings from this emerging research.

Learning Gains. Learning gains in science have been identified using epistemic games in structured, workshop-like settings. Across a number of studies, David Shaffer’s group has found positive gains in knowledge, skills, and attitudes through participating in their epistemic games in intensive summer programs as measured by traditional tests, clinical interviews, and concept maps (see Shaffer, 2006). In epistemic games, players as assume the roles of engineers,

[3] Henry Jenkins points out that the many connections to how game narratives operate and narratives in other media (ranging from amusement parks to comic books).

designers, planners, or journalists in an intensive multi-week summer program. Although not computer or video games per se, epistemic games are built around role playing, and frequently involve digital authoring tools such as*Soda Constructor*. Most recently, Shaffer and colleagues have begun doing network analysis of participants' actions in order to capture knowledge in situ, a potentially useful method for science educators interested in teaching processes such as investigation, argumentation, and design (see Rupp, Gushta, Mislevy, & Shaffer, in press).

Conceptual Change and Changes in Scientific Inquiry. Eric Klopfer (2008) and colleagues (see Colella, 1998) have used participatory simulations to teach about biology, virology, immunology, epidemiology, and scientific methods in a variety of formal and informal secondary school contexts. In participatory simulation games, players are participants in a system in which they might pass virtual diseases or bear offspring with particular genetic characteristics. The games are tuned to include latency in diseases or recessive genes so that players must conduct their own investigations to determine the causes of the outbreaks. Using concept maps, interviews, and survey instruments Klopfer has shown conceptual changes in how participants think about diseases and how they prioritize steps in conducting investigations.

Somewhat similarly, but on a bigger scale, in 2005, several hundred thousand of the 1.2 million users of*Whyville* contracted Why-Pox. *Whyville* is centered around science-themed mini-games and involves a virtual community consisting mostly of 8-16 year-olds. Why-Pox was a virtual epidemic launched in the community to study how the community responded to a virtual epidemic – a little like Klopfer's participatory diseases but spread out over hundreds of thousands of people. Why-Pox rampaged through the community, affecting Whyvillians with a small rash and bumps. Foley and La Torre (2004) found that this was quite engaging for many participants, with at least 1000 participants entering the Whyville "Center for Disease Control" website to learn about diseases and participate in online discussions – all in a voluntary context.

In their study of *Whyville* in a classroom scenario, Yasmin Kafai and colleagues (in press) studied how students experienced the events. They studied conceptual change among *Whyville* players and found positive changes in going from pre-biological toward biological causal models for understanding the events. Kafai also found changes in type 2 vocabulary, that is, vocabulary (such as "contamination") that is not "everyday" but also not entirely scientific (such as "E.coli"). Type 2 vocabulary has been shown to be critically important for struggling readers' success in school (see Beck, McKeown, & Kucan, 2002).

Interestingly, Squire (2009) also reported positive changes in type 2 scientific vocabulary among augmented reality game players. As players read and interpret documents they develop understandings of type 2 vocabulary. Through the course of the unit, they regularly use these terms in discussions, reports, and presentations as they role play as scientists. Students also gain proto-experiences of "authentic" (as opposed to contrived) investigative experiences, something critically important to science educators for communicating dispositions aligned with those of science. Although this study reported findings in classroom settings, this general pedagogical model of location-based games also has worked in museum and after school settings (Klopfer, 2008; Squire & Jan, 2007).

Event-Driven Learning. In reflecting upon the *Why-Pox* outbreak, Kafai, Feldon, and Fields et al. (in press) show how shared virtual experiences of such events can create shared experience, which can be the basis of shared communal membership, engagement, and learning (much as they are in *WoW*, which experienced a similar outbreak which Why-Pox was modeled after). Although other informal science structures such as robotics or programming competitions are also event driven, *Why-Pox* was unique in that it mobilized hundreds of thousands of youth in authentic inquiry in real-time to identify the cause of and to minimize the impact of a disease that was personally meaningful to them. This is the type of event and learning process that educators might want to exploit further. In informal learning environments where time scales are flexible, participation is voluntary, and multiple forms of participation can be used to integrate different ability levels (from long-term sustained participation to develop deep expertise to short-term experiences to raise interest), event-driven learning appears particularly useful.

Distributed Mentorship. Across these studies (even in studies that are entirely outside of school) researchers examined the impact of instructors and noted the importance of mentorship in learning. Nulty and Shaffer compared students with and without mentoring, and found in post-tests that students receiving mentorship performed much better than those not being mentored. Similarly, Kafai noted the importance of mentors in their study.

Many informal science educators hope that virtual worlds such as *Whyville, River City*, or *Quest Atlantis* may distribute teaching across the community (as in *WoW*) so that there are no "teachers" per se, but rather, a network of peers and mentors who coach one another. The Why-Pox example suggests that such mentoring *can* happen in spontaneously forming organizations, and at least in this instantiation, mentors were critical for producing conceptual change. Knowing that certain participant structures (such as "grouping mechanics") foster the collaborative problem solving known to be critical to learning in Massively Mulitiplayer Games, one can imagine their value in informal science education environments. However, to date those design features have not been sufficiently explored (Steinkuehler, 2005).

Role/Expertise Differentiation. A key opportunity for informal science education is to create contexts for collective participation without identical learning outcomes for each student

(Collins & Halverson, 2009). Informal science learning contexts can support the co-construction of learning goals between learners and designers. Learners can – and should – have significant opportunities to pursue interests, develop unique identities as consumers and producers of information (and thus media), and develop unique identities as "professionals" in domains.

Research suggests that role playing games are a good tool and context for creating such learning experiences. Shaffer's work, for example, emphasizes the active nature of role play in such settings, as people integrate knowledge, skills, attitudes, and identity under an epistemic frame. As players confront these increasingly challenging situations, they embark upon trajectories from novices to experts. Notably, there is frequently no one model "expert" within a given game community but multiple ways that one can perform "being an expert" (Steinkuehler, 2006). In their most advanced forms, games frequently include authorship opportunities for players with learning trajectories often leading toward legitimate participation in social relations beyond the game context itself.

Science as Science Civic Literacy. Today's global future requires an ever better public understanding of science. Today's key social and scientific issues (such as climate change, gene therapy, pandemics, or personalized medicine) require an informed populace capable of understanding scientific advancements as they develop (as opposed to learning "all they need to know" in school). Yet, scientific civic literacy rates in the US struggle to reach 20% (Miller, Pardo, Niwa, 1997). Miller (1998) articulated a framework of "scientific civic literacy" that may be particularly useful for informal science educators seeking to design games around key problems (like pandemics) that mobilize a citizenry toward action. Scientific civic literacy, according to Miller, requires:

1) An understanding of critical scientific concepts and constructs, such as ecosystems, the molecule, or DNA;
2) An understanding of the nature and process of scientific inquiry;
3) A pattern of regular information consumption; and
4) A disposition toward taking action to make change in one's lifestyle as necessary (adapted from Miller, 1998).

Many of the games described herein address these same goals. However, as a field, perhaps we have been too occupied with the notion of creating "professional scientists" rather than developing scientific civic literacy in our populace. Offering models of citizens who have "a disposition toward taking action to make change in one's lifestyle" may be more productive and beneficial than promoting scientific careers alone.

There is reason to hope that media can address this challenge. In a recent survey of scientific civic literacy, the consumption of informal science materials (science magazines, television programs, books, science websites, or museums) trailed only the completion of an undergraduate science course as a predictor of scientific civic literacy (Miller, 2001/2002). The participatory nature of games, which are hypothesized to create dispositions toward taking action in the world (see Thomas & Brown, 2007) may be particularly well suited to fostering this disposition.

Participants' Goal-Driven Learning: Whose Goals? A key opportunity for games-based researchers (and challenge for educators most familiar with formal educational situations) is that informal learning environments – like games themselves – ultimately are fueled by interest- or passion-driven learning. Informal science educators (like game designers) have the task of designing enticing learning experiences in which learners are *compelled* to learn more. The key difference may be best summarized by Klopfer's (2008) description of scientific mystery games at museums in which parents and student pairs *paid* money to attend game-based learning workshops. (How many students would *pay* to go to biology class?) A trick for game designers is to create learning experiences that leverage learners' interests and goals, address the needs of the umbrella institution, and respond to the concerns of science educators more broadly. Thus, whereas the development of student interests and identities is not a primary goal for schools, this may be crucial to informal science education.

Next Steps: Where to Go From Here

In 1956, Bell Labs Science films released "Our Mr. Sun," an educational film about the importance of the Sun for life on Earth. Written and directed by Frank Capra, this was the first of nine films that paired Bell Labs scientists with Hollywood talent, including the likes of Mr. Capra, Walt Disney, Jack Warner, Mel Blanc, and Sterling Holloway. The films, designed for primetime television, were an unqualified success. They were shown on television, then used in classrooms for over 30 years and now are sold on DVD for home and school use. The producers behind the series dubbed it, "Operation Frontal Lobe" to describe the power of media for supporting public understanding in science both in and out of schools (Jenkins, Klopfer, Squire, & Tan, 2003). Created in response to Sputnik, this series was but one example of many academic-industry partnerships designed bolster science education in the United States.

If science educators hope to play a leading role in the development games-based learning, rather than leaving it to the commercial enterprises, then new models of educational media development are needed. We need models that take serious the challenge of identifying intrinsically interesting aspects of games, the ways that games motivate learners, and how these can be integrated with science education goals. Creating compelling media of this sort demands partnerships among education, academics, and media in order to leverage the resources such games require. These assets aren't simply financial; professional knowledge about production processes and access to market research and distribution channels are needed. As Ito describes, the 1990s were ultimately marked by many educators being left out the conversation about educational games (mostly because they ended up researching Internet-based learning).

Given the fast-paced nature of scientific discoveries, a goal for game designers in informal science education may be to not look at "standardized" curricula that has gone through the lengthy state adoption processes, but rather, to take fresh approaches to the challenge of ensuring that our populace is capable of making good decisions about our futures, all the while taking lessons from curricula designed for formal settings. Free of many of the constraints experienced by school curriculum designers, informal educators have the opportunity to partner with scientists to create materials of direct and immediate interest to broad publics, effectively "bypassing" the unnecessary steps of federal, state, and schools bureaucracies. One can imagine learning systems like *Whyville* aimed at educating a populace about contemporary issues in science (including the nature of science as an enterprise) rather than simply "reteaching" school-based content in new ways. As recent political discussions suggest, the future of our democracy could depend on it.

References

Aldrich, C. (2003). *Simulations and the future of learning: An innovative (and perhaps revolutionary) approach to e-learning*. Pfeiffer.

Azevedo, F.S. (2006). *Serious play: A comparative study of engagement and learning in hobby practices.* Unpublished dissertation, University of Califorinai, Berkely.

Bagley, E.S., & Shaffer, D.W. (2009). When people get in the way: Promoting civic thinking through epistemic game play. International Journal of Gaming and Computer-Mediated Simulations. 1(1), 36-52.

Barab, S. A., Thomas, M, Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, A game without guns.*Educational Technology Research & Development,* 53(1) p86-107.

Brown, L. (1992). The new world order. *Changing Environmental Ideologies*, 19-35.

Brown, K. & Cole, M. (2002). Cultural historical activity theory and the expansion of opportunities for learning after school. In G. Wells & G. Claxton, (Eds.)*Learning for life in the 21st Century*, (pp. 225-238). Malden, MA: Blackwell.

Bruckman, Amy; Carlos Jensen, and Austina DeBonte (2002). "Gender and Programming Achievement in a CSCL Environment."*Proceedings of CSCL*, Boulder, CO, January 2002.

Carpenter, S.R., Armbrust, V., Arzberger, P., Chapin, T., Elser, J., Hackett, E., Ives, T. Kareiva, P., Leibold, M. Lundberg, P. Mangel, M. Merchant, N. Murdoch, W., Palmer, M. Peters, D. Pickett, S., Smith, K. Wall, D. Zimmerman, A. (2008).*The future of synthesis in ecology and environmental sciences.* Unpublished manuscript. Madison, WI: University of Wisconsin-Madison. Last retrieved September 17, 2009 from limnology.wisc.edu/media/Report_Synthesis_v10_FINAL.pdf

Chinn, C. A., and Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks.*Science Education 86(2):* 175–218.

Cole, M. and The Distributed Literacy Consortium. (2006).*The Fifth Dimension: An after-school program built on diversity.* New York: Russell Sage.

Colella V. (2000). Participatory simulations: building collaborative understanding through immersive dynamic modeling.*Journal of the Learning Sciences 9(4)*:471–500

Collins, A. & Halverson, R. (2009).*Rethinking education in the age of technology*. New York: Teacher's College Press.

Crowley, K. & Jacobs, M. (2002). Building islands of expertise in everyday family activity. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), Learning conversations in museums (pp. 333 - 356). Mahwah, NJ: Lawrence Erlbaum Associates. Gee, J. P. (2007).*Good video games and good learning: Collected essays on video games, learning and literacy* (1st Ed.). Peter Lang Publishing.

Edmonds, B. & Hales, D. (n.d.). *Computational simulation as theoretical experiment.* Report published by the Centre for Policy Modelling, Aytoun Building, Manchester Metropolitan University, Manchester, UK. Retrieved on 3 November 2003 from http://cfpm.org/cpmrep106.html

Feynman, R. (1985). *Surely you're joking, Mr. Feynman!: Adventures of a curious character.* New York: W. W. Norton & Co,

Foley, B. J. & La Torre, D. (2004). Who has why-pox: A case study of informal science education on the net. In Y.B. Kafai, W.A. Sandoval, and N. Enyedy (Eds.)*Proceedings* *of the sixth international conference on the learning sciences* (p. 598). Mahweh, NJ: Lawrence Erlbaum Associates.

Games, I.A. (2008) Three Dialogs: A framework for the analysis and assessment of 21st century literacy practices, and its use in the context of game design within Gamestar Mechanic. To Appear in *E-Learning 5* (4).

Games-to-Teach Team. (2003). Design principles of next-generation digital gaming for education. *Educational Technology*, 43(5), 17-33.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave/Macmillan.

Gee, J. (2007). *Good video games and good learning: collected essays on video games, learning, and literacy*. New York: Palgrave/Macmillan.

Hayes, E. & Gee, J.P. (forthcoming). The Sims challenges & game design literacies. Invited article for a special E-learning issue on Gaming Literacies.

Hayes, E.R. & King, E. M. (2009). Not just a dollhouse: what The Sims2 can teach us about women's IT learning. *ELearning, 17 (1),* pp 60 – 69

Horowitz, W.A. (1996). Developmental origins of environmental ethics: the life experiences of activists. *Ethics & Behavior, (6),* 29.

Holland, w., Jenkins, H. & Squire, K. (2003). Theory by design. In Perron, B. and Wolf, M. (Eds.). *Video Game Theory Reader* (pp. 25-46). London: Routledge.

Ito, M. (2003). *Engineering Play*. Unpublished Dissertation, Stanford.

Ito, M. Horst, H. Bittanti, M. boyd, d., Herr-Stephenson, B., Lange, P.G., Pascoe, C.J., Robinson, L. Baumer, S., Cody, R., Mahendran, D. Perkel, D., Sims, C. & Tripp, L. (2008). *Living andlLearning with new media: Summary of findings from the Digital Youth Project.* Chicago, IL: the John D. and Catherine T. MacArthur Foundation.

Jenkins, H., Klopfer, E., Squire, K. & Tan, P. (2003). Entering the education arcade. *Computers in Entertainment 1(1).*

Kafai, Y.B., Feldon, D., Fields, D. Giang, M. & Quintero, M. (in press). Life in the times of Whypox: A virtual epidemic as a community event. To appear in C. Steinfeld, B. Pentland, M. Ackermann, & N. Contractor (Eds.), *Proceedings of the Third International Conference on Communities and Technology.* New York, NY: Springer.

Kafai, Y.B., Heeter, C., Denner, J., Sun, J.Y (Eds). (2008). *Beyond Barbie and Mortal Kombat: New perspectives on gender and gaming.* Cambridge, MA: MIT Press.

Kirschner, P.A., Sweller, J. & Clark, R.E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry based teaching. *Educational Psychologist, 41*, 75-86.

Klopfer, E. (2007). Blurring Lines with Mobile Learning Games. *Educational Technology.*

Klopfer, E. (2008). *Augmented learning: Research and design of mobile eEducational games*. Cambridge, MA: MIT Press.

Klopfer, E. and Osterweil, S. (in press) The boom and bust and boom of educational Games. *Transactions in Edutainment.*

Klopfer, E., Scheintaub, H., Huang, W, Wendel, D. (2009) The Simulation Cycle - Combining Games, Simulations, Engineering and Science with StarLogo TNG. *Journal of E-Learning.*

Klopfer E., Yoon S., Perry J. (2005). Using palm technology in Participatory Simulations of complex systems: a new take on ubiquitous and accessible mobile computing. *Journal of Science Education and Technology 14(3)*:285–298.

Lemke, J. (1990). *Talking Science: Language, Learning, and Values*, Ablex Publishing, Norwood, NJ.

Miller, J.D. (1998). The measurement of civic scientific literacy. *Public Understanding of Science, 7(3),* 203-223.

McGonigal, J. (2007). Why I love bees: A case study in collective intelligence gaming. *The John D. and Catherine T. MacArthur Foundation Series on Digital Media and Learning* (pp. 199-227).

Miller, J.D. (2001) "The Acquisition and Retention of Scientific Information by American Adults," in J.H. Falk (ed.) *Free-choice Science Education: How We Learn Science Outside of School*, pp. 93–114, New York: Teachers College Press.

Miller, J.D. (2002) "Civic Scientific Literacy: A Necessity for the 21st Century," *Public Interest Report: Journal of the Federation of American Scientists* 55(1): 3–6.

Miller, J.D.; R. Pardo, & F. Niwa. (1997). *Public Perceptions of Science and Technology: A Comparative Study of the European Union, the United States, Japan, and Canada.* Madrid: BBV Foundation Press.

Nash, P., & Shaffer, D. W. (2008). Player-mentor interactions in an epistemic game: *A preliminary analysis. Paper presented at the International Conference of the Learning Sciences (ICLS),* Utrecht, Netherlands

National Research Council. (2002). *Scientific research in education.* R. J. Shavelson & L. Towne (Eds.), Committee on Scientific Principles for Education Research. Washington, DC: National Academy Press.

Nelson, B., Ketelhut, D. J., Clarke, J., Dieterle, E., Dede, C., & Erlandson, B. (in press). Robust design strategies for scaling educational innovations: The River City MUVE case study. In B. E. Shelton & D. A. Wiley (Eds.), *The educational design and use of computer simulation games*. Rotterdam, The Netherlands: Sense Press.

Nulty, A., & Shaffer, D. W. (2008). Digital Zoo: The effects of mentoring on young engineers. P*aper to be presented at the International Conference of the Learning Sciences (ICLS),* Utrecht, Netherlands.

Papert, S. (1987), Computer Criticism vs. Technocentric Thinking, *Educational Researcher, 16(1),* pp. 22-30.

Papert, S. (1998). Does easy do it? Children, games, and learning. *Game Developer*, June.

Peirce, C.S. (1877/1986). The Fixation of belief. In N. Houser & C. Kloesel (Eds.) *The Essential Peirce (V*ol 1, pp. 186-1999). Bloomington, IN: Indiana University Press.

Prensky, M. (2001). Digital Game-based Learning. New York: McGraw Hill.

Rosenbaum, E., Klopfer, E., and Perry, J. (2007). On Location Learning: Authentic Applied Science with Networked Augmented Realities. *Journal of Science Education and Technology.*

Rupp, A, Gushta, M, Mislevy, R, & Shaffer, DW. (in press). Evidence-centered design of epistemic games: Measurement principles for complex learning environments. *Journal of Technology, Learning, and Assessment*.

Resnick, M. Rusk, N., & Cooke, S. (1998). The Computer Clubhouse: Technological fluency in the inner city. *In D. S*chon, B. Sanyal, and W. Mitchell (Eds). *High Technology and Low-Income Communities.* Cambridge, MA: MIT Press.

Salen, K., & Zimmerman, E. (2003). *Rules of play*. Cambridge, MA: MIT Press.

Sawyer, B. (2006). In C. Weirauch, Games, more games. Military Simulation and Training Magazine, The International Defense and Training Journal Vol 3, pp. 20-22. Last retrieved September 17, 2009 from http://mst.texterity.com/mst/2006-3/?pg=21

Schaller, D.T., Goldman, K.H, Spickelmier, G., Allison-Bunnell, S., Koepfler, J. (no date). Learning In The Wild: What Wolfquest Taught Developers and Game Players. Institute for Learning Innovation, USA

Shaffer, D. (2006) *How computer games help children learn*. New York: Palgrave.

Shaffer, D.W. & Gee, J.P. (2005). Before every child is left behind: How epistemic games can solve the coming crisis in education, Wisconsin Center for Education Research, Madison, WI.

Squire, K.D. (2006). From content to context: Video games as designed experiences. *Educational Researcher, 35(8)*, 19-29

Squire, K. (2008). Designing Centers of Expertise for Academic Learning Through Video Games. *Theory Into Practice*, *47*(3), 240-251.

Squire, K. D., DeVane, B., & Durga, S. (2008). Designing Centers of Expertise for Academic Learning Through Video Games. *Theory Into Practice*, *47*(3), 240-251.

Squire, K. & Jenkins, H. (2004). Harnessing the power of games in education. Insight (3)1, 5-33.

Squire K.D. & Jan, M. (2007). Mad City Mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. Journal of Science Education and Technology, 16(1) 5-29.Steinkuehler, C. (2006a). Massively Multiplayer Online Video Gaming as Participation in a Discourse *Mind, Culture, and Activity*, *13*(1), 38-52.

Steinkuehler, C. (2006b). Virtual worlds, learning, & the new pop cosmopolitanism *Teachers College Record*, 12843.

Steinkuehler, C. & King, B. (in press). Digital literacies for the disengaged: Creating after school contexts to support boys' game-based literacy skills. Manuscript in preparation for *On the Horizon*.

Thomas, D., & Brown, J. (2007). The Play of Imagination: Extending the Literary Mind. *Games and Culture*, *2*(2), 149.

Steinkuehler, C.A. & Duncan, S.D (2008). Scientific habits of mind in virtual worlds *Journal of Science Education and Technology*, *17(6)*, pp. 530-543.

White, D. (2006). *Resilient Planet*. Unpublished Master's Thesis. Madison, WI: University of Wisconsin-Madison.

Yoon, S. & Klopfer, E. (2006). Feedback (F) Fueling Adaptation (A) Network Growth (N) and Self-Organization (S): A Complex Systems Design and Evaluation Approach to Professional Development. *Journal of Science Education and Technology*, 15(5-6), 353-366.

Sample list of software cited

Bridge Builder. (2000). Chronic Logic. Microsoft Windows, Mac OS X, Linux. http://www.chroniclogic.com.

Evolution. (2007). Free World Group. Adobe Flash. http://www.freeworldgroup.com

Evolution (1999). Discovery Channel Networks.

Fold.It. (2008). University of Washington Departments of Computer Science & Engineering and Biochemistry. Microsoft Windows, Mac OS X, Linux. http://fold.it/portal/

Immune Attack. (2008). Federation of American Scientists. Microsoft Windows. http://fas.org/immuneattack/

LOGO, (n.d.). Epistemology and Learning Group, MIT Media Lab.

Mad City Mystery. (2005). Local Games Lab. Mobile Devices. http://lgl.gameslearningsociety.org/games.php

MeCHeM. HAGames. Adobe Flash. http://www.hagames.com.

MindRover: The Europa Project. (1999). CogniToy. Microsoft Windows, Linux.

Nobel Prize. (2001-2009). Nobel Web AB. Adobe Flash. http://nobelprize.org/educational_games/

Operation: Resilient Planet. (2008). National Geographic & Filament Games. Microsoft Windows, Mac OS X. http://www.jason.org

The River City Project. (2002). Harvard University, Arizona State University, Active Worlds. Microsoft Windows. http://muve.gse.harvard.edu/rivercityproject/

Pontifex I and II. (2004-2008.). Chronic Logic.

SharkRunners. (2007). Discovery Channel. Adobe Flash. http://dsc.discovery.com/convergence/sharkweek/shark-runners/shark-runners.html

Quest Atlantis. (2001). Indiana University Center for Research on Learning and Technology. Microsoft Windows, Mac OS X.http://atlantis.crlt.indiana.edu/

Supercharged!. The Education Arcade. http://educationarcade.org/supercharged

StarLogo TNG. July 2008. MIT Scheller Teacher Education Program. Microsoft Windows, Mac OS X. http://education.mit.edu/drupal/starlogo-tng

Monopoly. (n.d.). Parker Brothers and Waddingtons.

SodaConstructor. (2000). Soda Creative Ltd. Java. http://sodaplay.com/creators/soda/items/constructor

Whyville. (1999). Numedon. Java. http://whyville.net.

Wolfquest. (2008). Eduweb. Microsoft Windows, Mac OS X. http://*www.wolfquest.org/*

World of Warcraft (2004). Blizzard Entertainment. Microsoft Windows, Mac OS X. http://www.worldofwarcraft.com/index.xml