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Games and Simulations in Informal Science Education

Kurt Squire and Nathan Patterson

This paper explores the possibilities and challenges games and simulations pose for informal science education. Three crucial opportunities (and related challenges) shape the field:

1. *Diversity of contexts, goals, and methods*. Informal science educators have the unique opportunity to pursue goals difficult to achieve in formalized settings—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, informal science educators operate in a variety of environments, from unstructured settings such as homes to highly structured settings such as workshops. This diversity in goals and contexts frees such educators, including educational game designers, to create experiences that appeal to students' personal interests and span home, school, and after-school contexts (and indeed *requires* them to do so). However, such diversity of context, goals, and methods for reaching those goals makes for a fragmented field that lies outside the purview of much of the contemporary discourse in education research (see National Research Council, 2002).

2. *"Outside the box."* Research, theory, and practical wisdom in informal science education largely arise in contexts outside the traditional domains of science education. For example, some of the most complex forms of scientific thinking in games can be found in commercial entertainment games with no overt educational goals at all. Further, so-called "edutainment" games have far larger budgets and scope—and much more polish—than most educational games and simulations, which are frequently developed in research contexts. However, edutainment games may also lack coherent models of educational game play, privileging marketing or commercial goals over educational values.

3. *Interest-driven, individualized learning*. Faced with the daunting task of competing with all other out-of-school interests, informal science educators seek methods of improving game and other educational designs to build and sustain learner interest and engagement, support learners in forming identities affiliated with science, and create lifelong interest in the field. In fact, in support of this goal design is proposed as a field in itself, rather than as a natural extension of learning theory. Research is needed on the impact on learning of games and simulations played in informal contexts. Yet the key features informal science educators seek to achieve—interest-driven learning, voluntary participation, divergent learning outcomes, connections across contexts—run counter to the underlying logic of many predominant research designs, such as randomized controlled trials.

We begin with a brief overview of the recent history of games and games research. We then attempt to clarify the distinctions between games and simulations. Next, we examine types of informal learning environments—*structured* informal learning environments such as workshops and after-school programs and relatively *unstructured* learning environments such as home and online environments—contrasting them with more formal learning environments such as school. We then turn our focus to research on learning across these contexts. We conclude by offering some thoughts on the opportunities and challenges for informal science education with games.

Games: A Brief History

The educational games released in the 1980s and early 1990s did not for the most part reflect prevailing educational concerns and thus were not researched extensively. Ito (2009) characterized the games of this era as falling into three genres: edutainment, entertainment, and authoring games:

> 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. (p. iv)

Ito described 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 failing to integrate content and game play, having poor production values, and generally “dumbing down” for educational audiences (Holland, Jenkins, & Squire, 2003; Klopfer & Osterweil, in press; Ito, 2009; Papert, 1998; Squire, 2006; Squire & Jenkins, 2003).

The most robust program of research on this era of games was undertaken by the Fifth Dimension Project (Brown & Cole, 2002; Cole & the Distributed Literacy Consortium, 2006; Ito, 2009). *The Fifth Dimension* is a role-playing meta-game based around existing commercial off-the-shelf computer games. Fifth Dimension research emphasized the centrality of *context* in determining how participants appropriate such software. Different encompassing institutions (from libraries to schools) implant their own participant structures in the software, influencing its appropriation. Children’s own voices and goals also co-constitute how the games are (or are not) appropriated as tools, as they may place their own cultural framings of video games, toys, or other cultural categories upon games (Ito, 2009). Papert’s (1987) research on Logo likewise emphasized the importance of context, reminding educators that it is ill-advised to research “Logo” directly, but rather, one always researches Logo implemented for particular reasons in particular contexts.

A new generation of games built on learning sciences principles and contemporary developments in the commercial video games industry seeks to reinsert complex problem solving into games. Indeed, a host of new games—many quite good by most accounts—suggest the potential for creating immersive learning experiences in which core game play is tied to academic practices in science (Gee, 2003, 2007; Klopfer, 2007; 2008; Shaffer, 2006; Squire, 2006).

Dozens of science-based learning games—including *Whyville*, *WolfQuest*, *Foldit, Operation: Resilient Planet*, Nobel Prize games, *River City*, *Evolution*, *Pontifex*, *MindRover*, *Immune Attack*, *MeCheM*, *Sharkrunners*, *Quest Atlantis*, *Supercharged!*, *Mad City Mystery*, and *StarLogo TNG*—have been developed to support science learning in formal or informal contexts. Some of these have come from academia, and others from entertainment or commercial contexts. Research on such games remains scant, however, and the research that does exist has predominantly been conducted by educators working in formal education settings. As a result, the goals 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 to understand the challenges and opportunities facing science educators.

Games and Simulations

Distinctions and Ambiguities

Before further going further, it is worth considering what is meant by games and simulations. *Games* are sets of rules that are temporarily adopted for the purposes of entertainment. While playing *Monopoly*, for example, we agree to assign a value to taking turns rolling dice and moving pieces, trading *Monopoly* money, and so on. Some games, *Monopoly* included, are a blend of written and "house" rules, with players writing 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.

The distinctions between games and simulations can blur, however. For example, *Monopoly* is a game in that it has rules that players adhere to for enjoyment, but it could also be regarded as a simulation in that it takes the real estate market and by representing it through a set of materials (dice, squares, and player symbols), reproduces simple behaviors and results observed in the real world. Critics might note that *Monopoly* does not seem a particularly *good* real estate simulation, and in fact they might be right, depending on what *Monopoly* was specifically purported to be a simulation *of* and for what *purpose*. If one wanted to predict the 12 months of real estate values in Southern California following the subprime crash, *Monopoly* would not be especially useful. On the other hand, if one wanted to show an 8-year-old the basic idea of how monopolies stifle competition, *Monopoly* might be a start.

For many, the more consequential differences between games and simulations relate to who developed them (i.e., the game community or the simulation community) and for what purposes they are deployed (see Weirauch, 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 backward. Game designers, in contrast, tend to focus on *enhancing the player's experience* and are willing to "cheat," by intentionally reducing model accuracy, in order to achieve this goal. Prensky (2001) described how military simulation developers were "blown away" when they played the entertainment versions of 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 orientation to development have led to different development tools, programming practices, and ultimately products (Prensky, 2001; Weirauch, 2006).

Similar distinctions can be made between *high-* and *low-fidelity* simulations. Instructional designers maintain that low-fidelity simulations are often most desirable for learning. High-fidelity simulations are typically computationally expensive and potentially confusing to newcomers.

Convergences: Modeling and Design

A further distinction may be made between idea and predictive simulations (Edmonds & Hales, 2005). Whereas *predictive simulations* are most often used for planning—either in social policy (e.g., what is the fate of Social Security under current conditions?) or the natural sciences (e.g., will it rain tomorrow?)—*idea simulations* offer insights into a particular idea and, as such, have an entirely different set of "success criteria."

Idea simulations are often valued for their elegance and explanatory power with relatively few variables (see Carpenter et al., 2009). 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, predators begin dying as well. The reduction in predators creates, in turn, an overabundance of prey. Then, the prey begin to die off as the predator population rebounds and predators overfeed. These fluctuations continue, and the Lotka-Volterra model shows how such fluctuations result in spikes in both predator and prey populations, enabling ecologists to make sense of their observations in the world.

As a mode of inquiry, gaming differs in fundamental ways from model building (or modeling). Modeling involves the recursive process of observing phenomena and building representations to illustrate core ideas (also called abductive inquiry; see Peirce, 1877/1986). Models such as Lotka-Volterra are constructed by *scientists* through 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 game play (Gee, 2003; Squire, 2005). This mode of learning is also *abductive*, however, in that players are forced to amend their understandings of how the world works as they encounter new experiences.

Although modeling and gaming seem distinct enough to keep separate, paradigms of game-based learning often deliberately try to blur them. Games such as *GameStar Mechanic* and game design curricula seek to create series of tight, integrated loops of playing and designing (Games, 2008; Mathews & Wagler, 2010). This learning-through-gaming model that integrates game *play* and game *design* capitalizes on the agency provided by game authoring packages, while also guiding the learner in a way most open-ended approaches do not. As such, the model 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 a robust understanding of the particular domain (Kirschner, Sweller, & Clark, 2006).

The results of research on these more recursive play-design styles of games are still emerging, and more evidence is needed before we will know the extent to which they address the limitations of constructivist and inquiry-based approaches. This said, games do offer one model for teaching learners the knowledge, skills, and attitudes needed for more open-ended tasks (Shaffer & Gee, 2005). The learning cycle in games involves players in 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 the sequence (Aldrich, 2003; Ito, 2009; Salen & Zimmerman, 2003; Squire, 2006). Studies of *Sims* and *Civilization* players have shown that as the players learn the underlying rules of the system, they can use editing tools to change those rules in order to explore ideas or match their play style (Squire, DeVane, & Durga, 2008; Hayes & Gee, in press). Indeed, as players become literate with game creation tools, they can use them to create their own modifications or indeed their own games (Games, 2008; Hayes & Gee, in press; Squire, 2008).

Informal Learning Environments

Structured Informal Learning Environments

Informal science education is unique in that it is 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 pursuing goals germane to institutional interests. In designing local games for learning with informal science education partners, Squire, Wagler, Mathews, et al. (2007) sought to achieve educational goals ranging from instilling a sense of civic ownership over local lakes to fostering environmental ethics. Common goals of science educators include increasing the diversity in science and promoting national science literacy (Miller, 1998; National Research Council [NRC], 2009). Many factors are known to increase interest in science, including curiosity about topics (such as dinosaurs), hobbies (such as radios, model airplanes, or video gaming), experiences of natural places (such as lakes), and relationships with loved ones (Azevedo, 2006; Crowley & Jacobs, 2002; Feynman, 1985; Horwitz, 1996). Building games that leverage such factors is a natural route for designers of games in informal settings to pursue.

Informal science organizations are varied—from local ecology groups to national associations of scientists—and thus generalizations can be difficult. However, a report of the National Research Council (NRC, 2009) has made a strong case for viewing informal science education as having six facets:

1. Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.

2. Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.

3. Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

4. Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.

5. Participate in scientific activities and learning practices with others, using scientific language and tools.

6. Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science. (p. 4)

These six facets apply to all science education contexts, but the NRC report emphasized the unique capacity of informal science education to increase interest in science and encourage affiliation with science as an enterprise (building identities in science). Of course, any medium—from books to lectures—may address these facets in any number of ways. Moreover, given the history of educational media research (see Clark, 1983), researching games in *conjunction* with other media is a better approach than comparing games or examining them in isolation. The NRC report emphasized the importance of the media as a *tool* for informal science education (used to achieve various goals) and as a *context* for studying science. Scientists have reported that experience with diverse media—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, Heeter, Denner, & Sun, 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 the case of *Operation: Resilient Planet*. *Resilient Planet* is a scientific role-playing game developed by Filament Games for classroom use, but it is also a free download available on the National Geographic website. One can easily imagine how it might be tied to a museum installation or issue of local importance.

Resilient Planet players are scientists investigating a decrease in monk seals in a marine reserve in Northwest Hawaii. Driving an underwater vehicle, they track, photograph, and count 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 a series of arguments, they expand their notions of scientific phenomena, argumentation, and the nature of scientific inquiry.[1]

Table 1 illustrates how *Resilient Planet* embodies the six NRC facets. Games such as *Resilient Planet* suggest the great potential of games in informal science education contexts. However, like many educational games, *Resilient Planet* was designed to be used in schools. As such, it is only a few hours long, it is relatively linear, and by design it lacks some features—such as more open-ended game play, more collaborative problems, and stronger connections with scientific communities of practice—that one might want in an educational game.

[1] As an example of the issues that are addressed by "cheating" in game design, *Resilient Planet* originally included a "realistic" ecology of predators and prey in which species reacted to the player and one another in realistic ways. After weeks of experimentation, the game designers concluded that they could create an ecosystem that functioned "well 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*.

Table 1
Facets of Informal Science Education and Ways They Are Addressed in **Resilient Planet**

Facets of informal science education[a]	Ways addressed in *Resilient Planet*
1. Experience excitement, interest, and motivation to learn about natural and physical phenomena.	The game leverages an intrinsically interesting aspect 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; on scientific processes, concepts, and institutions; and on their own learning.	The game includes multiple types of 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.	Players assume roles as one of four different types of scientists.

[a]Adapted from NRC (2009).

The NRC report (2009) on informal science education contexts emphasized their unique opportunities and constraints. Table 2 compares the attributes of informal and formal educational settings as they pertain to games. These comparisons are not intended to put informal settings “in response” to formal settings; informal settings may be every bit as important as formal settings in people’s attitudes toward and experience of science (Barron, 2006; Crowley & Jacobs, 2002; NRC, 2009). Also, there are evident differences in how formal educational institutions are structured; Milwaukee, Wisconsin, alone has more than 40 charter schools with a smorgasbord of constraints. However, informal science educators, although they cannot rely on compulsory attendance laws to require participation, generally have more freedom in the topics they pursue, the ways in which they pursue them, and 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 constraints, Squire et al. (2008) described their attempts to build systemic ecological-economic thinking among *Civilization* game players in an after-school gaming club.[2] This curriculum aimed to tie together ecological, economic, and political concerns around a gaming series based on global sustainability (Brown, 1992; Diamond, 2005; Durga, in press). Such a curriculum may be difficult to implement in schools that teach biology but not ecology and that do not link either field to economics or political science. DeVane et al. adapted *Civilization* to consider issues such as 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, the Squire et al. curriculum based on *Civilization* had to compete with other activities such as basketball, cooking, and scouts. Moreover, many students resisted taking pre- or posttests, particularly if they "smelled like school," making assessment difficult—a phenomenon reported elsewhere in the literature (see Hayes & King, 2009; Steinkuehler & King, 2009). As a result of such challenges, informal educators are much more concerned with building and sustaining student interest than most formal educators (NRC, 2009).

Informal settings also offer opportunities for students to develop highly individualized interests and pursuits. Researchers investigating analogous programs in informal information technology settings have found students developing deep interest and expertise in areas ranging from computer programming to historical modeling (Bruckman, Jensen, & DeBonte, 2002; Resnick, Rusk, & Cooke, 1998; Squire et al., 2008). The communities created in these settings—like games culture in general—are built on a valuing of *expertise* (Squire et al., 2008). Background or credentialing matter less than the ability to meet (and at times push the boundaries of) community norms.

[2] *Civilization* is a historical simulation game in which players lead a civilization over a time period, managing its utilization of natural resources, development of cities and their production capabilities, and pursuit of strategic goals.

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 the intersection of the participants' interests, the affordances of the game, and the pathways made available within the game-playing community (Bruckman et al., 2002; Squire et al., 2008; Resnick, Rusk, & Cooke, 1998).

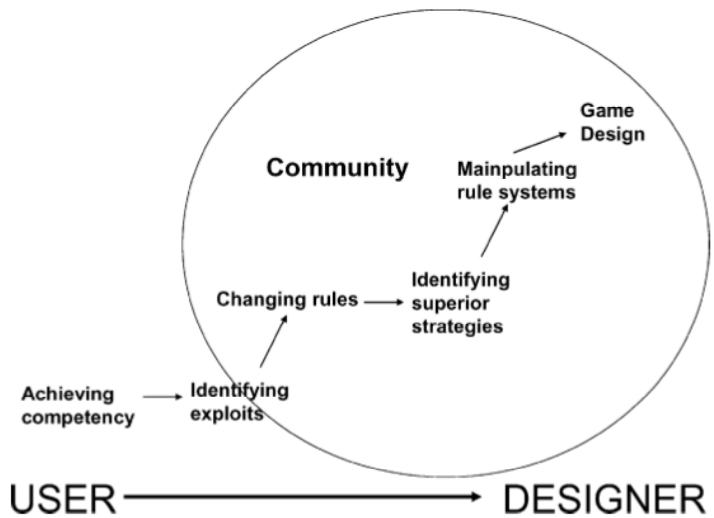

***Figure 1.* Trajectories of experience from user to designer among gamers.**

Even in the most highly 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, prespecification of learning objectives, isolation of variables). As a result, researchers working in informal settings have frequently preferred case studies or other methods that enable them to collect 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 creates challenges. It is difficult, for example, to administer a uniform task to multiple participants and obtain meaningful results. One immediate direction researchers might pursue to understand patterns of behavior across broader numbers of participants is to use methods such as nonparametric statistics. However, the underlying contradiction between user-defined learning goals and uniformity of treatment still needs to be addressed.

"Unstructured" Informal Learning Environments[3]

In their ethnography of youth media producers, Ito et al. (2008) described three levels of youth participation in new media: (a) using new media to extend existing friendships with peers ("hanging out"); (b) exploring new media to gain new skills ("messing around"); and (c)

[3] The word *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.

pursuing an intense engagement with new media in a specialized area of interest ("geeking out"). This trajectory enables participants to enter media production cultures in unthreatening ways and provides multiple pathways toward developing expertise. Currently, educators are exploring potentials for designing informal learning spaces (such as a downtown library) based on these principles, literally mapping out informal learning centers so that they are designed to promote these three activities (hanging out, messing around, and geeking out) and the fluid movement 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.

Design-based researchers have, however, begun to map out ways of meshing forms of scientific thinking with game play, avoiding many of the previous problems with science games that involved game play mechanics non-congruent with, or even counter to, the ways of thinking encouraged in science (Klopfer, 2008; Schaller, Goldman, Spickelmier, Allison-Bunnell, & Koepfler, 2009; Squire & Jan, 2007). Because informal science educators must compete with all the other demands on youth (athletics, video games, television), they need sophisticated models of what constitutes academically engaging game play. Design, which is at times given a backseat to other forms of inquiry within education research, is of the *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 (e.g., *Foldit*, *Resilient Planet*, *WolfQuest*), opportunities exist for educators to study these designs and their effects on players more formally.

Some of the most compelling research on the potential of games to support deep scientific thinking has taken place completely outside the realm of educational games. For example, Steinkuehler and Duncan (2008) studied 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 found 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 complex pursuits. Although not all *WoW* forum participants necessarily build their own models in an attempt to reverse-engineer the game world, *WoW* forums function to model a type of discourse congruent with those of scientific argumentation. The work of Steinkuehler and Duncan reminds us that this sort of reverse-engineering is a form of scientific inquiry (abductive reasoning; see Peirce, 1877/1986). However, a potential pitfall arises because game worlds are intentionally programmed by designers and operate according to built-in mathematical rules, and those 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.

This line of research further reminds us of the importance of moving beyond the study of learning from a particular game to the study of *how* learning occurs through gaming. Effective models of educational gaming may be created by designing compelling, multilayered challenges and spaces for coordination and argumentation (see also *I Love Bees*, a game that allowed players to experience being part of a massively collaborative knowledge network; McGonigal, 2007). Such spaces recruit players from multiple ability levels and diverse backgrounds, creating numerous opportunities for formal and informal apprenticeship.

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

The examples discussed thus far show some of the ways that scientific thinking is naturally supported by games and suggest how games may be particularly well suited to informal learning environments. Scholars of different education paradigms have begun to provide explanations for the learning potential of games and simulations in such environments. These studies have considered participatory simulations, epistemic games,[4] role-playing games for citizenship, targeted games, and investigative role-playing games in multiplayer virtual environments (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Colella, 2000; Nelson, Ketelhut, Clarke, Dieterle, Dede, & Erlandson, 2007; Games-to-Teach Team, 2003; Klopfer, 2008; Klopfer, Yoon, & Perry, 2005; Shaffer, 2006; Squire, 2006; Squire & Jan, 2007; Yoon & Klopfer, 2006). These explanations tend to emphasize the interactive nature of games, particularly how they function as worlds for players to inhabit and explore rather than as traditional stories to be interpreted.[5] Design research on educational games has emphasized 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 they have great potential for fostering 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 in homes and 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, Shaffer and colleagues have found that participation in their epistemic games has resulted in positive gains in knowledge, skills, and attitudes as measured by traditional tests, clinical interviews, and concept maps (e.g., Shaffer, 2006). In epistemic games, players assume the roles of professionals—for example, engineers, designers, planners, or journalists—in an intensive, multiweek 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*.[6] 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, 2010).

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[4] See the Learning Gains section for further discussion of epistemic games.

[5] Jenkins (with Squire, 2003) has pointed out the many connections between game narratives and narratives in other media (ranging from amusement parks to comic books).

[6] sodaplay.com/

Conceptual Change and Changes in Scientific Inquiry

Klopfer (2008) and colleagues (see Colella, 2000) 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 these participatory simulations, players are participants in a system in which they might pass on virtual diseases or bear offspring with particular genetic characteristics. The games are modified appropriately 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, Klofper 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- to 16-year-olds. Why-Pox was a virtual epidemic launched in the community to study how the community responded—a little like Klopfer's virtual diseases, but spread out over hundreds of thousands of people. Why-Pox rampaged through the Whyvillian community, causing rashes and bumps on players' avatars. Foley and La Torre (2004) found that the virtual epidemic was quite engaging for many participants, with at least 1,000 entering the Whyville "Centers 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 setting, Kafai and colleagues (Kafai, Quintero, & Feldon 2010) studied how students experienced the virtual epidemic. They studied conceptual change among *Whyville* players and found positive changes—specifically, movement from pre-biological to biological causal models for understanding the events. Kafai also found changes in Tier 2 vocabulary—that is, vocabulary (such as *contamination*) that is not "everyday," but that also does not reach the level of scientific terminology (such as *E. coli*). Tier 2 vocabulary has been shown to be critically important for struggling readers' success in school (see Beck, McKeown, & Kucan, 2002).

Interestingly, Squire (2010) also reported positive changes in Tier 2 scientific vocabulary among augmented reality game players. As players read and interpret documents, they develop understandings of Tier 2 vocabulary. Over the course of a 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) investigation. Although Squire's study reported findings in classroom settings, the general pedagogical model of location-based games also has proved successful in museum and after-school settings (Klopfer, 2008; Squire & Jan, 2007).

Event-Driven Learning

In reflecting upon the *Why-Pox* outbreak, Kafai, Feldon, Fields, Giang, and Quintero (2007; see also Kafai et al., 2010) showed how such virtual events can create shared experiences, which can be the basis of shared communal membership, engagement, and learning (much as they are in *WoW*, which experienced an outbreak that was similar to—and served as the model for—Why-Pox). Although other informal science structures, such as robotics or programming competitions are also event-driven, *Why-Pox* was unique in that it engaged hundreds of thousands of youth in authentic inquiry in real time to identify the cause and 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. For example, Nulty and Shaffer (2008) investigated the role of mentoring in the epistemic game *Digital Zoo*, finding in posttests that students receiving mentoring performed much better than their unmentored peers. Similarly, Kafai, Feldon, Fields, Giang, and Quintero (2007) noted the importance of mentors in their study.

Many informal science educators hope that virtual worlds such as *Whyville*, *River City*, and *Quest Atlantis* will 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 multiplayer games, one can imagine their value in informal science education environments. However, to date, those design features have not been sufficiently explored (Steinkuehler, 2006b).

Role/Expertise Differentiation

Informal science education offers the critical opportunity to create contexts for both collective participation and customized learning (Collins & Halverson, 2009). In particular, informal science learning contexts can support the co-construction of learning goals by learners and designers. Learners can—and should—have significant opportunities to pursue interests and to develop unique identities as consumers and producers of information (and thus media) and as "professionals" in domains.

Research suggests that role-playing games are a good tool and context for creating such learning experiences. Shaffer's work (Bagley & Shaffer, 2009; Shaffer, 2005, 2006), for example, emphasizes the active nature of role play in such settings, as players integrate knowledge, skills, attitudes, and identity under an epistemic frame. As players confront increasingly challenging situations, they embark upon a trajectory from novice to expert. Notably, there is frequently no one model "expert" within a given game community, but rather multiple ways that one can perform "being an expert" (Steinkuehler, 2006a). 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 Civic Scientific Literacy

The global future requires an ever better public understanding of science. Today's key social and scientific issues (such as climate change, gene therapy, pandemics, and personalized medicine) require an informed populace capable of understanding scientific advances as they develop (as opposed to learning "all they need to know" in school). Yet, rates of civic scientific literacy in the U.S. struggle to reach 20% (Miller, Pardo, & Niwa, 1997). Miller (1998) articulated a framework for civic scientific 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. Civic scientific literacy, according to Miller, requires:

1. An understanding of critical scientific concepts and constructs, such as ecosystems, the molecule, and 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.

Many of the games described in this paper foster these qualities. However, as a field, perhaps we have been too occupied with creating "professional scientists" rather than with developing civic scientific literacy in our populace. Offering models of citizens who have "a disposition toward taking action to make change in their lifestyles" 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 civic scientific literacy, the consumption of informal science materials (science magazines, television programs, books, science websites, and museums) trailed only the completion of an undergraduate science course as a predictor of civic scientific literacy (Miller, 2001, 2002). The participatory nature of games, which are hypothesized to foster taking action in the world (see Thomas & Brown, 2007), may be particularly well suited to fostering this disposition.

Goal-Driven Learning

Informal learning environments—like games—ultimately are fueled by interest- or passion-driven learning. This characteristic represents a key opportunity for games-based researchers (and a challenge for educators in formal educational settings). Informal science educators, like game designers, have the task of designing enticing learning experiences in which learners feel *compelled* to learn more—as in the scientific mystery games parent and student pairs *pay money* to attend at museums (Klopfer, 2008). (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, it may be crucial for informal science education.

Next Steps: Where to Go From Here

In 1956, Bell Laboratories 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 prime-time television, were an unqualified success. They were used in classrooms for more than 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 of 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 to bolster science education in the United States.

If science educators hope to play a leading role in the development of 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 seriously the challenge of identifying intrinsically interesting aspects of games—the ways that games motivate learners—and exploring 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 are not simply financial; professional knowledge about production processes and access to market research and distribution channels is needed. As Ito (2009) has described, the 1990s were ultimately marked by many educators being left out of the conversation about educational games (mostly because educators were focused on collaborative learning online).

Given the fast-paced nature of scientific discoveries, game designers need to take fresh approaches to the challenge of ensuring that the populace is capable of making good decisions about the future, all the while taking lessons from, but not designing around, 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 lengthy state curriculum adoption processes. 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 on the importance of a 21st-century workforce suggest, the future of our democracy could depend on these new approaches.

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