

# Role playing games for scientific citizenship

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Received: 4 March 2012 / Accepted: 4 March 2012 / Published online: 29 March 2012  
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**Abstract** Research has shown that video games can be good for learning, particularly for STEM topics. However, in order for games to be scalable and sustainable, associated research must move beyond considerations of efficacy towards theories that account for classroom ecologies of students and teachers. This study asks how a digital game called *Citizen Science*, built using tropes and conventions from modern games, might help learners develop identities as citizen scientists within the domain of lake ecology. We conducted an expert-novice study, revealing that games literacy was a mediating variable for content understanding. In a follow-up classroom implementation, games literacy also operated as a variable, although students drove the activity, which mediated this concern. The teacher devised a number of novel pedagogies, such as a field trip, in response to the unit. We found evidence for the most powerful learning occurring through these activities that were reinforced via the curriculum. Students were most engaged by *Citizen Science*'s most "gamelike" features, and learners took up the core ideas of the game. Users also reported the experience was short of commercial gaming experiences, suggesting a tension between game cultures for learning and schools.

**Keywords** Science education · Curriculum · Pedagogy · Reform processes · Assessment

## Resumen

Diversas investigaciones han mostrado que los video juegos pueden ser beneficios para el aprendizaje, particularmente en temas relacionados con ciencia, tecnología, ingeniería y

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Lead Editor: C. Milne

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matemáticas. Sin embargo, para que los video juegos puedan ser sostenibles y para que su impacto se pueda utilizar a gran escala, los juegos y las pedagogías asociadas a estos deben moverse más allá de mediciones de eficacia, hacia teorías que den cuenta de las ecologías del aula, en las que participan estudiantes y profesores. Este estudio investiga como un video juego diseñado acuerdo a las convenciones de los juegos contemporáneos, podría ayudar a los estudiantes a desarrollar identidades como *ciudadanos científicos* dentro del dominio de la ecología de lagos.

Llevamos a cabo un estudio de experticia que comparaba expertos en ciencia con estudiantes. Allí, encontramos que la alfabetización en video juegos era una variable mediadora en la comprensión de los contenidos, y que la experiencia previa con video juegos influenciaba la interpretación que se hacía del video juego utilizado en este estudio (*Citizen Science*). En implementaciones de aula posteriores, se encontró que la alfabetización sobre video juegos también operaba como una variable, pero que esta preocupación se moderaba porque los estudiantes podían auto-dirigir una parte importante de la actividad de aprendizaje. El profesor desarrolló varias pedagogías novedosas, como por ejemplo salidas de campo a un lago cercano, para complementar el uso del video juego. Encontramos además evidencia de que el aprendizaje más interesante sucedía a través de estas actividades que eran reforzadas vía currículum. Adicionalmente, encontramos que los estudiantes estaban más interesados en los elementos de *Citizen Science* cercanos a los atributos tradicionales de los video juegos, y que los aprendices asimilaron las ideas centrales del juego. Los usuarios también reportaron que la experiencia fue menos buena que la experiencia en los juegos comerciales, sugiriendo una tensión entre las culturas de juegos para el aprendizaje y para las escuelas.

En conjunto, estos estudios sugieren que las preferencias de profesores y jugadores, el conocimiento previo, y las experiencias anteriores pueden influenciar la interpretación del video juego. Dar cuenta de la diversidad en los estudiantes podría ser particularmente importante al momento de crear juegos que intenten usar las ventajas del genero, y estos sistemas deberían ser respaldados por una importante actividad derivada del currículo para lograr los objetivos educativos. Igualmente importante es que, aunque los estudiantes prefieren usar juegos en el aula (en oposición a los textos tradicionales), no todos los estudiantes o profesores están lo suficientemente familiarizados para disfrutar los video juegos homogéneamente. Esto implica que dar cuenta de la experiencia previa con video juegos que, como se mostró influencia el uso de los video juegos en el aula, será esencial no solamente para diseñar nuevos video juegos sino para desarrollar evaluaciones digitales anidadas en estos.

There has been a recent growth of support for using video games and simulations for science education. A recent article in *Science* argues that video games provide a route to large-scale science, technology, mathematics and engineering (STEM) education (Mayo 2009). A report by the National Research Council (NRC 2010) summarizes how video games have the capability of catalysing and advancing educational reform, and even the President of the United States has explicitly asked for the development of more educational video games that teach STEM topics (Gibbs 2010). In addition to facing the same challenges of widespread adoption as other new education interventions, we argue that educational digital games must not only move beyond theories that reduce digital games to a vehicle for content delivery, but also must bring with them a constellation of new literacy practices, including material, symbolic, and social transformations. In short, researchers need to ask what *new* meanings are made possible through games, as well as how they might continue to support more traditional literacy practices.

Broadly, digital games have been shown to provide exciting and powerful new ways for teaching science (Steinkuehler, Squire, and Barab 2011). Leveraging technological affordances such as real-time 3D display physics simulation and collaboration, video games have created compelling environments in which learners solve problems authentic to a domain using complex tools and resources. They have been used to help improve students' conceptual understanding of topics such as electromagnetism (Clark, Nelson, D'Angelo, Slack, and Martinez-Garza 2009), water quality (Barab et al. 2005), and ocean science (Saini-Eidukat, Schwert, and Slator 2002) and to raise student interest in science topics and careers (Dede and Ketelhut 2003). As an NRC (2010) report summarizes, "simulations and games have potential to advance multiple science learning goals, including motivation to learn science, conceptual understanding, science processing skills, understanding of the nature of science, scientific discourse and argumentation, and identification with science and science learning" (NRC 2010, p. ES-2).

This paper is a series of two research studies: One, an expert-novice study to understand how players make meaning from the experience, and the second, a classroom implementation study that investigates learning through playing the game, *Citizen Science*, in a classroom setting. The expert novice study seeks to investigate if playing *Citizen Science*, engenders scientifically valued ways of thinking (e.g., science as argument; Kuhn 1993) so that assessors might discern between experts and novices through in game action (criterion-related evidence for validity). The following implementation study investigated how meanings were made when the game was played in a 4-day pilot curriculum, enabling us to better understanding its pedagogical affordances and limitations. In both cases, we describe a tension within games-based pedagogy. Representing scientific phenomenon through the medium of games requires material, symbolic, and social configurations that were confusing to expert, non-game playing scientists, but familiar to non-scientist game players. Adventure game mechanics were valued by gamers and conducive for learning, creating interesting questions about how to best design educational games for social institutions such as schools that not only do not honour, but also are constructed *against*, these literacy practices.

## Digital games for science education

One of the most powerful theoretical arguments for digital games as a pedagogy is Jim Gee's (2005) notion of *embodied empathy for complex systems*. Gee argues that games enable the opportunity to enter complex systems, take actions within them, and understand how complex systems operate through testing how they respond to our actions. Gee argues that this view of games dovetails nicely with modern cognitive conceptions of the mind as networked simulation engines. From this view, the mind operates less like a computer, and more like a networked simulation that is constantly weighing choices and options, seeking to predict the outcomes of given actions and choices (see also Barsalou 1999).

Science educations such as Andrea diSessa (2000) and Ken Forbus (1997) have also argued for intuitive understandings as a productive route for developing robust scientific understandings (particularly in Physics, although it could apply across scientific domains). Forbus argues for the value of a strong foundation of good scientific intuitions about phenomenon before teaching more formalized representations (such as equations). diSessa's theory of p-prims is similar to this notion of deep intuitive grasps of phenomena, but diSessa extends the theory to interrogate the nature of symbolic representation in scientific understandings, how these understandings interact with the material world and

how knowledge is constructed (which he calls the three pillars of literacy). Perhaps not surprisingly, both diSessa and Forbus have used interactive digitally simulated environments as a context for building, refining, and testing these theories.

Work in the nascent area of games + learning + society (see Steinkuehler, Squire, and Barab 2011) seeks to build on this foundational work, but also to ask how games as popular media may *transform* how we learn. Media (from books to digital games) carry with them not only meanings, but particular ways of framing or representing the world (see Squire 2006). Digital games are built on a logic of simulation in that they represent content not as facts or narratives, but as worlds. These worlds are interacting rule sets that encode designers' intentions and provide the framework in which players operate. As players form goals, devise strategies to reach those goals, and monitor their success, they develop mastery over particular actions. As such, games require an expertise that is somewhat unique, although what forms that expertise takes, how it is valued socially and made sense of, is often negotiated through communities that support, nurture, and legitimize these performances.

As players learn through these interactions (material, symbolic, and social), they may develop design expertise, meaning they understand the basic and emergent properties of the system *and* they understand the strategic and aesthetic importance of design elements. Many expert players advance toward game design activities, either as careers in the games industry, through leadership roles (such as guild leaders), or in associated development fields (technology, design, programming, writing). If digital games can sell us the fantasy of learning skills, experiencing mastery, and designing new experiences for others, might educators try to do the same?

Indeed, the most dramatic educational potential of these worlds may be these experiences that they enable, and science educators might ask, "What kinds of experiences should our students have in science related domains?" *Citizen Science*, the project described in this paper, begins with the premise that every student ought to have the experience of using scientific understandings to shape the world. In terms of content knowledge, every student should understand that ecological forces operate across time and distances, so that manure dropped in a stream might cause increases in phosphate levels downstream 20 years later. Similarly, every student should understand that scientific argument is based on evidence and argument, and have experiences using evidence to make claims. If game players can save entire planets from ecological destruction or restore family farms, why can't schools provide similar experiences in which students use scientific understandings to develop skills that are valued outside of game contexts?

The premise of providing students with an experience that allows them to use scientific understandings, which shape a world, aligns broadly with current theoretical and practical citizen science movements. Such contemporary notions of civic science curriculum include highlighting the importance of addressing the way in which science content is learned, a distinct shift away from current assessment practices which tend to focus exclusively on content (Mueller and Tippins in press). And while some elements of citizen science programs focus on student generation of scientific knowledge (e.g. the *Environmentors* program) others, like ours, work towards generating civic-science literacy, including both the consumption of scientific information (Shen 1975) as well as the ability and motivation to engage in civic action. The goal of *Citizen Science*, the game, is to encourage democratic participation in society by providing students with the perspective that they are capable of acting as legitimate sources of science-driven community activism.

This paper presents observations from our first pilot studies with *Citizen Science*, an adventure game in which the player is a young adult who becomes concerned about the

health of a local lake threatened by eutrophication. Players gather data, confronting common naïve conceptions about the causes of eutrophication, travel through time to learn about the historic causes of the lake's current condition and what was done about them, and eventually argue to restore the lake to a condition more suitable for human use. In this study, we (1) tested the game with experts and novices in a think aloud setting, and (2) studied the game being implemented in a pilot curricular enactment. We draw on observations, student interviews, and teacher interviews to illuminate the challenges that educational science games may face as they enter classrooms, especially concerning the role of video game literacy. We argue that it is important to consider not only the difference between home and school gaming contexts, but also the prior experiences and preferences of students who are held as captive participants as similar to Devane and Squire (2008), we argue that what students bring to the table plays a role in how they interpret and subsequently experience our game.

### Digital games in schools

Before turning to *Citizen Science* and this study, it is worth briefly considering digital games in their historical context. Although the last decade of research on digital games points toward the new opportunities that such games might enable, placing digital games in a socio-historical context highlights the challenges that educators face bringing this and similar systems into schools. Our paper will argue that digital games based on contemporary theories of learning may face challenges that have previously received little attention. That is, as video games require not only students but also teachers to learn with the game as a system, new approaches to curriculum design may be required. Further, new assessment models may be required if we cannot simply rely on reproducing expert models of cognition.

Adventure games like *Citizen Science* have been around since the 1980s and were the topic of early studies on the potential of digital game-based learning. Citing their rich problem spaces, narrative, and interactivity, researchers documented the specific affordances of adventure games in an attempt to determine properties that might be useful for education purposes (e.g. Cavallari, Hedberg, and Harper 1992). These studies often stemmed from cognitive psychology and they often used traditional experimental methods to compare intervention efficacy based on factors like motivation (Malone 1981) and in general skill constructs like problem solving (Ju and Wagner 1997) which are problematic from a situated view (see Hickey and Schafer 2006). Further, difficulties associated with holding specific variables constant in complex learning environments understandably made the collection of clear evidence challenging (Ju and Wagner 1997).

Though cognitivist theories are still being tested and applied to video games, there has been a recent adoption of social theory, where games and learning are considered inherently social and inextricable from culture (see Gee, 2003). As digital games researchers seek to design learning environments that leverage digital games and their cultures, they must also become *curriculum* designers, bringing with them assumptions, values of learning and education, and the politics behind their interventions and ways of framing the world (Barab et al. 2007).

The challenges behind introducing and achieving broad adoption of interventions that are technologically and pedagogically disruptive are well noted. Computers must be current, must have appropriate software installed, and often be connected to the Internet or networked locally. Teachers may require professional development, both technically and

pedagogically. School administrators and parents must also value these new programs, allowing faculty the flexibility to overcome the hiccups that new technologies inevitably face. Indeed, video games face many of the same hurdles of their educational predecessors. van Eck (2006) summarizes these hurdles, further noting the problem of aligning the game with curriculum and content, the need for financial and technical support and the required infrastructure that educational settings must maintain.

Research on educational games and technologies suggests that some form of broad adoption is indeed possible, but requires particular sensitivity to the ecological factors that constitute the enactment of a learning intervention (Cole 1996). In other words, a theory of design cannot prescribe what it is or how it will be adopted and adapted *prima facie*. Rather, through cycles of design, enactment, and modification, tools eventually become integrated into practice and (hopefully) transform them as well (Brown and Campione 1996). *Fifth Dimension* (5thD), for example, is an after school program designed for a diverse student population to enable them to play and learn, fostering intellectual, social, and academic development in concordance with socio-cultural learning theory. Despite the costs associated with site upkeep, 5thD still exists more than 15 years after its inception. One of the (many) reasons behind its success is a commitment to iterative cycles of design, enactment, and research in order to understand the nature of a learning program, its consequences, and opportunities for transforming local practice.

Thus, educational game designers face a tricky set of contradictions: On the one hand, they want to suggest, even advocate particular design experiences and ways of appropriating technologies. On the other hand, they want to honor local autonomy, teacher professionalism, and recognize that any intervention is necessarily a component of a broader activity system (see also Squire, MaKinster, Barnett, and Barab 2003). This sequential set of studies (experts and novices playing *Citizen Science*, a redesign of the game and a subsequent classroom enactment study), seeks to navigate these emergent contradictions toward building a game engaging for players that embodies scientific practice and that might also transform classroom practice.

### **Citizen science: a game for identification with scientific citizenship**

The game begins. You are a 14 year-old girl. You stand dockside on Lake Mendota in Madison, Wisconsin (WI) watching some children playing and swimming. Your father approaches, walking your dog Raven. As Raven, a Labrador, jumps into Lake Mendota, time suddenly freezes and an apparition appears. “Stop,” she implores. If Raven swims she will die. The player soon learns that it is a “no swim day” due to high levels of blue-green algae, a real affliction in Lake Mendota caused by excessive phosphorous levels. Right away, the player uses this information (admittedly gathered simply as received knowledge, as opposed to constructed knowledge developed through experience), to convince your father to stop Raven. A Polaroid flashes, depicting your character playing with your father and Raven in the future, you see that you changed history.

This basic cycle: Confront challenge, gather data, argue with characters, observe results, and change the world constitutes the core game mechanic of *Citizen Science*. The game is broken up into two major narrative parts. In the first part of the game, players travel back through time to a 1960s version of Madison, WI. They uncover and solve pollution problems faced by Lake Mendota with the help of a fictional lake spirit and talking muskrat. In the second part, players return to the present time and discover that the future of Lake Mendota continues to be threatened by eutrophication. Players must gather data

from around Lake Mendota and connect it to data generated from a realistic simulation to convince legislators to promote the planting of agricultural buffer strips along waterways, and the setting of limits to the amounts of agricultural run-off farms can produce. The final argument involves several layers of more focused nested arguments, multiple data points from multiple sources, and managing of large evidence inventories.

Aesthetically, *Citizen Science* tries to use the tropes, mechanics, and aesthetic stylings of American Adventure and Role Playing Games (RPG) (Fig. 1). Like American adventure games, *Citizen Science* characters use humor, plot twists, embedded tools, time travel, and self-referentially discuss the game experience. Like a RPG, *Citizen Science* uses pets, fantasy characters, and spirits to create an otherworldly experience.

The goal of *Citizen Science* is to give players experiences of having confronted pressing ecological issues, conducted scientific inquiry to address these issues, and taken action in the (virtual) world to affect change. The game does *not* ask players to become professional scientists, but rather, to adopt the lens of science within a worldview similar to their own so as to enact changes that they might see as useful. The goal is to leverage what Gee (2003) describes as games' potential for projective identity formation, so that players experience some of what it would be like to use science to make a difference in the world. Rather than "project" a professional identity on to the student, it seeks to create a space for the formation of a hybridized identity in which the player does science—not just for personal or economic gain—but as a "power fantasy" in which they actually affect the world. This hybridized identity arises from the combination of the player's virtual identity, or whom they are playing within the game, and their real identity, or whom they are as an individual playing the game at a given time in a given place similar to Gee's notion (2003). Identity can be thought of as driven by social interaction, enacted by a player embedded within a cultural context (see Mead 1934), so a player's hybridized identity takes into account the individual and the fictional character they control thereby extending and operationalizing



**Fig. 1** *Citizen Science*, developed by Filament Games with Matt Gaydos and Kurt Squire

Gee's (2003) notion of hybrid identity. Our goal in *Citizen Science* was to encourage the player to experience a world similar to their own in which the actions and values held by their avatar are educationally desirable. Rather than attempt to align the students' identity with a professional field, as is often the case in science education, we attempted to align the game protagonist's identity with the student's. The goal for *Citizen Science* was to provide students with an opportunity to take on the role of an active agent of change who uses science to achieve realistic goals that are of local importance in the world and for students to be able to reflect on the game experience with respect to their own identity.

Underlying *Citizen Science* is a social theory of learning in which ultimately, the player forging an identity as a skilled participant in social practice who uses information to solve problems is more important than mastering knowledge or skills alone. Of course, one cannot be a skilled participant without some mastery of particular knowledge domains and skills (in this case lake ecology and argumentation), which are admittedly simplified and stripped down. Nevertheless, as students learn how to take action within their own community, perhaps they may become inspired to actually do so, and in future work we intend to investigate how in-game actions can lead to civic engagement. In the pilot and this initial study, however, our goal was to first understand how the game, teacher, classroom, and students interacted.

The underlying methodological approach of our work is design-based research (DBRC 2003). As such, our overarching goal includes the iterative creation and testing of *Citizen Science* as a cultural artifact and intervention in order to effectively implement it within real-world settings. Design-based research allows us to not only account for contextual elements that may not have apparent to initial theoretical claims, but can help test and generate theories that inform learning within inherently complex systems.

### **Pilot expert/novice study: gaming lake science content**

After the first year of production, we began a series of user studies in order to better understand: How users interacted with interfaces, what meanings they made from their game experiences, and whether actual domain-related experience could predict game performance (criterion-related evidence for valid assertions about learning through participation in the game, see (Messick 1993)). Our intention in using the think-aloud protocol was to differentiate between expert and novice cognition that occurred during game play (Ericsson and Simon 1992) in order to generate evidence of the forms of thinking game play was eliciting. We sought to capture the forms of thinking that arose in game play in order to characterize the nature of the game experience, and further analyze its capacity to function as a performance task. As such, the evidence gathered, which is based on inferences made through observations of game play performance, serves as both content and criterion related evidence for the validity of assessments (Messick 1993). Consistent with Messick's analysis (1993), we treat validity as a unitary construct and in this case sought evidence to support the argument that playing *Citizen Science* could ultimately enable researchers to make claims about student/player expertise in citizen science as it pertains to inland water ecology.

#### **Listening to experts and novices**

We began by conducting a study of experts and novices. Three experts in lake science/civic action and four students/experienced gamers were asked to participate in an un-structured

pre-interview, think-aloud while playing *Citizen Science*, and a post interview. The purpose of the think-aloud protocol was to differentiate between expert and novice cognition that occurred during game play (see Ericsson and Simon 1992) while interviews focused on participants' video game and technological background as well as on their general reception of the game play experience. The three experts included one teacher who had created multiple lake ecology curricula and two Department of Natural Resources employees who worked on environmental policy and local outreach surrounding the lakes. The three students were recruited from a local alternative high school. Each interview took approximately 90 minutes. All domain experts reported casual video game play, such as solitaire or Wii Sports. Students reported more extensive play, including adventure and massively multiplayer role-playing games, first person/third person shooters. Researchers intervened as much as requested to help participants learn the game interface, its tools, and to answer any questions. Researchers also occasionally interrupted when there was a clear bug, interface problem, or obstacle preventing the player from reaching her goals, once the cause was clear.

One researcher reviewed each session and wrote field notes. Each researcher then selected key portions of the transcript for transcription. In data analysis sessions, researchers used the constant comparative method to review notes, generate themes, look for confirming and disconfirming evidence, and select data passages for more intense analysis.

The data selected, transcribed and analyzed here was selected to illuminate research questions and is generally representative of the interactions occurring. We analyzed these data with a blended verbal analysis framework (an approach for examining in-game clickstream data alongside the verbal utterances from a talk aloud protocol, cf. Card et al. 2001). Figures 1 and 2 present representative screen shots of the types of activities carried on in the game.



**Fig. 2** An embedded model that players can use to test theories about Lake Mendota

Each of the novice scientists (but expert gamers) completed all four of the arguments, while the expert scientists (but novice gamers) completed on average 2.5 arguments before giving up (after about 90 minutes, which was longer than most novices took). They opened and closed the argument interface (referred to in-game as the “arguizer,” a tool with which the player constructs arguments) on average four times, indicating hesitancy and perhaps frustrations with the interface. Minimally, these results give educators cause to pause when considering using games such as *Citizen Science* as a tool for inferring meaning, as one or more variables interfered with experts’ ability to make arguments. The following analyses makes explicit what occurred during game play.

#### Thinking aloud: gaming literacy interacts with content expertise

The first exchange begins with the novice player (S2) opening the arguizer. The player is on the second argument, which is that zebra mussels are bad. She asks herself which one that is, and hovers her mouse over bits of evidence and arguments, reading and re-reading their contents. By 35:57, she has (quickly) generated a successful argument, although she does not use it yet. She describes her actions confidently, and looks for more evidence to bolster her argument. Soon the conversation turns into an interactive design feedback session as she notes that she can not add more support, but intones that perhaps she should be able to do so. The interviewer explains the interface (acknowledging ambiguity), and the participant interrupts him at 36:33 to affirm that the expert was correct, thus repositioning herself as a knowledgeable authority on design. In this utterance, she also uses the game feedback (the fact that it will not accept further evidence) as feedback that she has sufficiently completed the argument.

This participant quickly became comfortable with the interface, game mechanics, and underlying game model to the point where she began suggesting game improvements to the researchers and anticipating later features that were planned for development but not yet implemented. For example, at about half an hour (36:40) into the game play session she suggested an interface improvement (enabling more supporting evidence to be added). Shortly after (36:50) she described a game mechanic that exists in later levels—the ability to anticipate and refute a counter argument (e.g. “zebra mussels should not be introduced to lakes *although studies have shown that zebra mussels can reduce turbidity*”). Then for the next few minutes, the player cited her own experience with lakes as the source of her knowledge, before finally completing the in-game argument she had been working on successfully. She talked briefly about her father who fished, and although she did not describe herself as particularly interested in lake ecology (she was more prone to social issues, such as right to life campaigns), she expressed some concern for ecological stewardship.

This participant made several moves characteristic of the participants who were novice in science, but expert in game play. First and foremost, she used the game interface as a scaffold for learning the underlying system. For example, she used mouse-overs—placing her mouse cursor atop on-screen object without clicking—as a tool for gathering feedback about her actions and the underlying game model. The researcher became a resource to guide her actions, and she had little problem describing issues she had with the interface and ways that the game could be improved, drawing on her expertise as a game player. Finally, she completed the entire argument in about two hours and 30 minutes, with about half of that time dedicated to a digression on her knowledge of lake ecology (see Fig. 3).

In contrast, Fig. 4 describes a typical expert scientist interaction. The expert hesitates, interrupting herself at 37:35 as she opens the arguizer, suggesting hesitancy with the

| DATA SELECTIONS |                                                                                                      | ANALYSIS                                                                                                                                                         |
|-----------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| S2              | 0:35:41.4 ((Arguizer_Open "Zebra mussels are bad"))                                                  | Quickly generates successful argument but doesn't use it yet.                                                                                                    |
| S2              | 0:35:46.8 >so which one is that?<                                                                    |                                                                                                                                                                  |
| S2              | 0:35:47.2 >that's "don't swim in the lake"< (9.4)                                                    | Wants to improve her already correct argument. Begins to reframe talk from 'think aloud' monologue to Interactive design feedback session.                       |
| S2              | 0:35:57.1 and i want to:o (.) take this (.) and aa:dd this for support. (8.1)                        |                                                                                                                                                                  |
| S2              | 0:36:13.1 ((Arguizer_Close))                                                                         | Interrupts 'expert' interviewer to affirm that his answer is correct. Repositions herself as knowledgeable authority on design.                                  |
| S2              | 0:36:13.6 >ok can i< <add more support?>                                                             |                                                                                                                                                                  |
| S2              | 0:36:14.6 ((Arguizer_Open "Zebra mussels are bad"))                                                  | Continues new interaction frame by suggesting improvements to a game interface.                                                                                  |
| S2              | 0:36:17.8 >ok i can add more support.< (.)                                                           |                                                                                                                                                                  |
| S2              | 0:36:21.3 maybe not                                                                                  | Provides an example of how this new mechanic would work. Her suggestion mirrors an already-existing game mechanic that exists in a level she has not yet played. |
| I               | 0:36:23.1 At=at some point it will you.                                                              |                                                                                                                                                                  |
| I               | 0:36:26.0 I don't know if it does here.                                                              | Successful argument completion                                                                                                                                   |
| I               | 0:36:27.2 : You might try:= >cl-click back on the-the uh one thing with the plus one argument again< |                                                                                                                                                                  |
| I               | 0:36:30.9 >and see if the add support<                                                               |                                                                                                                                                                  |
| I               | 0:36:33.6 >no it doesn't<, so i guess that one's [fine]                                              |                                                                                                                                                                  |
| S2              | 0:36:34.2 cus) at-at that part (its all done)=right! (4.8)                                           |                                                                                                                                                                  |
| S2              | 0:36:40.9 because here? it would be a really good spot to ha=to be able to put another one in?       |                                                                                                                                                                  |
| S2              | 0:36:46.5 because um (.) zebra mussels are bad.                                                      |                                                                                                                                                                  |
| S2              | 0:36:51.2 >because 'they can attach themselves to boat hulls and propellers causing damage'?         |                                                                                                                                                                  |
| S2              | 0:36:55.2 although (.) 'studies have shown that zebra mussels de=decrease lake turbidity'. (1.0)     |                                                                                                                                                                  |
| S2              | 0:37:01.2- ((Extended discussion of S2's experiences with 0:38:14.9 lakes))                          |                                                                                                                                                                  |
| S2              | 0:38:14.9 ((Argument_Success "Zebra mussels are bad"))                                               |                                                                                                                                                                  |

Fig. 3 Novice scientist excerpt data and analytic notes

interface and underlying mechanics. Like the science novice, she reads aloud. However, the expert scientist rejects the game's potential evidentiary explanations based on her own interpretations of the evidence. As she reads evidence she does not try to "fit" either piece of evidence into the tool and "try it to see if it works" as a way to learn about the system. Rather, she reads two pieces of evidence and closes the tool to abandon the problem (37:59). The expert's speech is colored with frequent pauses punctuated by tentative speech in which she thinks aloud and prolongs words (see 37:50; 37:56; 38:05) and collects her thoughts.

| Actor | Time      | Speech/Game Act                                                               |                                                                                                 |
|-------|-----------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| S7    | 0:37:35.6 | O:kay^ >let's see if< there's any more ah="can attach=                        | Incomplete/interrupted utterances show concentration on a challenging task.                     |
| S7    | 0:37:36.6 | ((Arguizer_Open "Zebra mussels are bad"))                                     | Locus of attention in-game.                                                                     |
| S7    | 0:37:39.1 | they're bad for the lake cus they atta=damage props                           | Rejects game's 'correct' evidentiary explanation based on interpretation of evidence.           |
| S7    | 0:37:41.4 | Uh, I guess that's not really a lake= show- (.6)                              | Rejects alternative evidence based on content knowledge, but does not try either.               |
| S7    | 0:37:45.2 | Decrease= lake turbidity= lake= declea- decrease lake's turbidity isn't ba:ad | Frequent, tentative pauses in 'think aloud' to collect thoughts.                                |
| S7    | 0:37:50.9 | it's just (.) what they do after that oh- (3.2)                               |                                                                                                 |
| S7    | 0:37:56.5 | *(or no oh) we're gonna go here* (3.0)                                        | Abandons problem momentarily.                                                                   |
| S7    | 0:37:59.0 | ((Arguizer_Close))                                                            |                                                                                                 |
| S7    | 0:38:01.4 | An:nd (what's this uhh) protesters are blocking the pa:ath? (.)               | Looks for spatial ways to avoid argumentation challenge.                                        |
| S7    | 0:38:05.4 | The only thing blinking is this down he:ere? (.)                              | Frequent prolongation of words signifies uncertainty in utterance.                              |
| S7    | 0:38:07.5 | so:o I guess that's where I go:o.                                             | Misinterpretation of game interface for activity scaffold. Surrenders authorial agency to game. |

Fig. 4 Expert scientist data excerpt and analytic notes

The expert attempts to avoid the impasse (or puzzle choke point) by physically avoiding the obstacle, but it does not work, suggesting an unfamiliarity with adventure game mechanics that require players to solve puzzles before moving forward. The passage ends at 38:07 with the expert misinterpreting the game interface and “going along” with what the game wants. Rather than interrupting to ask for help, criticizing the game, or using trial-and-error to see what would work, the expert scientist positions the *game* as expert. Note that consistent with best practice in usability studies, the same opening protocols were given to all participants. It took several minutes and many prompts before the expert successfully completed the puzzle in which an argument must be constructed to dissuade non-player characters from introducing zebra mussels into the lake, despite their relative expertise in the matter.

Several mediating variables may have caused the expert’s confusion, including a lack of familiarity with games, self-efficacy in a game-based environment, and negative transfer due to the expert “knowing” which answer she wanted to select, but not knowing how she could obtain it. However, it is intriguing that whereas the novice (like all novice players we studied) quickly positioned herself as an expert in which she knew how to play games, learn interfaces, and correct the game in areas in which it was lacking, at no point here, nor anywhere in the exercise, did the experts criticize the game for being incorrect or poorly designed.

In short, whereas novice scientists understood the material system of games and the symbolic system of the game interface, expert scientists did not. This pilot study suggested that educators designing educational games and hoping to use them as tools for inferring players’ learning must consider the mediating variable of games literacy. For example, content experts could easily articulate why zebra mussels are bad outside the game, they struggled to do so using the game’s argument constructor. Alternately, student gamers leveraged their gaming competencies straightforwardly to achieve their in-game goal.

Our pilot was originally intended to examine differences between expert and novices in terms of play styles, and to make a case for generating inferences based on in-game data. Instead, it pointed to the importance of games literacy as a mediating variable in the interpretation and construction of meaning within the game-space similar to previous studies on games literacy (Games 2008). Alex Games’ (2008) triadic theory of games literacy emphasizes “games” as arising at the intersection of the artifact, designers’ intentions, and communities of players with understood ways of interpreting the game (not unlike diSessa’s “social” pillar). Anthony Partington (2010) also continues in the same vein, arguing that a model of literacy as functional and detached from its cultural practices does not sufficiently include the relationship between game players and their lived culture.

In the debriefing sessions, the novice scientists expressed enthusiasm for seeing the full game developed using the same aesthetic style. All were familiar with Japanese Role-Playing games (which *Citizen Science* builds upon) and enjoyed these features, especially the *Spirit of the Lake*. The *Spirit of the Lake* is a physical manifestation of the overall health of Lake Mendota (much as one might create a “Gaia” creature to symbolize the Earth’s health). Experts reported mixed reactions to the Spirit of the Lake. Whereas some (especially experts) were concerned that the Lake could create misunderstandings, some (especially a younger Limnologist PhD) thought that it was a useful shorthand representation for capturing the lake’s state and in fact resonated with her own understanding.

With sufficient evidence that the game could promote identification with scientific citizenship and evidence that it could promote thoughtful reflection on issues in lake science, we approached a middle school teacher about constructing classroom exercises based on *Citizen Science*.

## Classroom study context

The following case study occurred at a small private K-20 school near Madison, WI. The four-day enactment included observations and interviews of students, the teacher, and an administrator with whom the teacher had previously worked. On day one of the four-day intervention, students participated in an introduction activity and played *Citizen Science*. Day two was dedicated to *Citizen Science*. On day three, the classroom conducted a field trip investigation of the lake. Day four was game wrap up and a quick debrief. *Citizen Science* was intended to be the focal point of a 2–4 week curriculum, but before this implementation we wanted to see what features teachers valued, which aspects of the game students responded to, and what opportunities existed for extending learning so as to dovetail with teacher interests.

### Participating teacher

The participating teacher was recruited based upon his experience working with project staff on previous projects using augmented reality games. In previous curricular enactments, researchers were relatively hands-on, helping to create lesson plans, facilitating the technology's use, and even teaching classes. For this study, we sought to maintain a relatively distant level of participation by acting primarily as technology facilitator and resource, allowing the teacher the freedom to design a classroom activity around the game however he wished. We exchanged a series of emails with him to answer any questions he might have and met with him twice before the classroom implementation to ensure that he felt comfortable using the game. The game was given to him approximately three weeks in advance.

### Students

Twenty-one (12 male) middle school students participated in the classroom study. From a survey administered after game play, most (14) students were found to play games at least two to three times a week with five of these students reporting playing video games daily. Students reported playing a variety of games including *Go Fish*, *Solitaire*, *Poker*, and *Scrabble* as well as a number of relatively sophisticated, M-rated video games including *Call of Duty*, *Left 4 Dead*, and *Uncharted 2*.

## Organizing a study in a classroom

For this study, we employed a case study approach (Stake 1995) in which researchers deliberately scaled back involvement and sought to understand what transpired within the case. Researchers were participant observers, but erred on the side of watching classroom activities unfold. The research questions included: What needs (both stated and inferred) does the teacher try to address? How does the teacher experience the game and how does this shape the curriculum? What meanings do players make from the experience?

### Observations

One researcher attended all (4) class periods, and two researchers attended each of the two sessions in which the game was played. The entire enactment was digitally video recorded both by the teacher for his records as well as by researchers. Researchers paid particular

attention to segments when participants appeared visibly frustrated or happy. Researchers also noted the nature of cross-student talk, particularly when students had questions or episodes from their games, which they wanted to share.

### Interviews

A total of four group interviews were conducted. Two group interviews were conducted with the teacher and an administrator one week before the intervention. A third de-briefing interview including the teacher, the administrator, and a teaching assistant was conducted on the first day and a final debrief interview was conducted including the teacher and the administrator on the final day. In addition, hour-long pre and post interviews were conducted with three students, but only one matching set of data was obtained.

### Surveys

After game play, students took a brief survey about their gaming experience and reaction to the game play. The survey instrument, consisting of a mix of 14 open and closed ended items and was intended to explore and triangulate themes and work within the classroom context. Twenty-one participants participated in the study and responded to the survey.

## Data and results: the pros and cons of genre adherence

The unit was judged to be a success by the teachers and the students. Overall, participants enjoyed *Citizen Science*. The game raised their interest in science, and students' concepts of the key scientific issues (the nature of watersheds) became more sophisticated. Consistent with the pilot study, the student group (novice scientists, but expert gamers) played the game successfully, enjoyed adventure game mechanics, and used game experiences to improve their understandings.

### Expert versus novice experience of citizen science

The difference between how experts and novices approached the game was exemplified during *Citizen Science's* introduction. The teacher, Don Taylor (a pseudonym) introduced *Citizen Science* through a whole group introduction and demonstration. Mr. Taylor began demonstrating the game, but within a few minutes had difficulty navigating the interface. The class began yelling instructions and soon Mr. Taylor abandoned the demonstration and let them play.

The students immediately began playing independently, something that Mr. Taylor later described as good. He explained how students often took greater initiative and ownership in such individualized, technology-enhanced units. He largely let students drive the experiences from here onward, directing students toward one another for resourcing when help was required.

### Engagement

Due to time constraints, an engagement-specific instrument was not administered. Students were vocal throughout game play, however about enjoying the game, for example

high-fiving one another and saying things like “this game is awesome.” In addition to our observations, we administered a brief post-game survey. Over half (11/21) students responded that playing *Citizen Science* was “more fun” fun than normal class activities (another 8 responded that it was about the same). Fourteen participants (66%) were definitely (5) or maybe (9) interested in playing more at home—even though the majority had already completed the game.

In open-ended responses, there was no single dominant aspect of *Citizen Science* that participants enjoyed the most or least. Some of the mechanics that students found to be most difficult or annoying (such as arguments) were others’ favorites. For example, three (14%) respondents mentioned that evidence and arguments were their favorite part of the game and three (14%) described it as their least favorite part of the game. Each participant mentioned a specific design feature that they enjoyed. Responses varied from using the secchi disk (a tool used to measure water clarity), to meeting characters, to saving the lake. In fact six of 21 students (28%) responded that *Citizen Science* was harder than typical schoolwork, and another 12 responded that it was about the same. Only three respondents (14%) reported that *Citizen Science* was easier than typical science instruction.

Consistent with contemporary theories of learning in games that emphasize the close relationship between problem solving, pattern matching, pleasure and learning (Gee 2003), several occasions arose in which players were engaged, frustrated, and wrestled with scientific issues embedded within the game. The exchange presented below is emblematic of this sequence. This exchange begins with the first student (S1) asking about the argument tool. He is wrestling with the same interface issues described in the expert-novice pilot studies in which players must learn to use interface queues as feedback on their success. S1 begins by asking what the color red signifies. S2 (Erich) gives a response, which gathers the attention of S3.

S1: Erich, if they’re all red does that mean they’re (.)

S2: This one, this one. Click that, I know, click to although (.)

S3: Wait that, most of those. Wait (.) How did you get the information there? How did you get the how did you get the, how did you get the information Erich?

S1’s simple question about the interface gives reason for students to consult one another’s screens. As S3 overhears, he observes that S2 has unlocked features that he does not have and is instantly intrigued. The conversation continues, however, with S2 giving directions, while S3 wants Erich’s attention to help him.

S2: Confirm now go argue.

S3: Erich (S1) man, Erich!

S1: (Reading) Wow man, that is heavy.

S3: Erich, How did you get last piece of information there?

S1: Oh the thing. Now I can go to the secchi disk reading.

S1: I get to go on a boat! Oh I’m so excited.

S3: Erich how did you get the last piece of information? Do I have to talk to the lake spirit?

S1: No. You have to go to the...

S3: Wait where did you get it?

S1: Talk to the girl.

A collaborative knowledge sharing space emerged among sub-groups of players (usually clustered groups of three) that monitored one another’s games. Many groups played *entirely* collaboratively, swapping across games and computers in a manner similar to that

reported elsewhere (see Squire, DeVane, and Durga 2008). Collaborative cross talk required players to use game vocabulary, such as *secchi disks*, for effective communication (see DeVane, Durga, and Squire 2010). Cross-talk also advertised possibilities to players, and students readily shared their progress and accomplishments with others in the classroom. By the end of the exchange, S1 breaks through his problem, is audibly excited about using the secchi disk and riding on the boat, repositioning himself as a knowledgeable player by directing S3 to “talk to the girl” to get past his dilemma.

After about three minutes, player S2 broke the silence announcing a question, showing also how acknowledging gaps in understanding was socially valued. Whereas in most school activities one is not encouraged to express difficulty, in game-based learning spaces, acknowledging challenges can be a sign of expertise. S3 interrupts the discussion with questions and S2 guides him through. This exchange shows how moments after solving the puzzle, S2 had some understanding of the argument. He walks S3 through the evidence and arguments without hesitation.

S2: I don’t understand.

S3: Wait Martin (S2), will you tell me how to get this one off?

S2: I got all the information. So you put mussel shells clutter the beach if you don’t already have that one. That one. This. No look for the one that mussels are natural, I don’t know if you have it. Yeah put that one down there And then change because to although, no, yeah. Although, confirm.

S2: Now what I supposed to do once I got these secchi disk readings?

The exchange ends with S2 again asking what he should do once he has the secchi disk readings, and because no one in his vicinity had solved that puzzle, his request went unanswered. In many respects, the classroom cross talk resembled an Internet gaming forum in which players share frustrations, recap moves, and ask for further information, suggesting how games—particularly when teachers let go of control over the entire group can redefine classroom interactions toward new learning cultures (Steinkuehler and Duncan 2008).

Though *Citizen Science*’s designers intended the game to include more Role Playing Game elements, such as character customization, we were unable to integrate these features given the budget and time constraints. Instead, *Citizen Science* draws on the adventure game genre, and includes (attempts at) humorous characters, Easter Eggs (such as hidden areas), and difficult puzzles that may take many attempts to solve, all of which serve to advance a narrative. We were uncertain how these mechanics would affect learning (especially given well known critiques of this genre). In this class, puzzle mechanics annoyed some players who saw them as difficult, annoying, or “not fun”, which is not surprising given the waning popularity (in some circles) of adventure games and the integration of adventure game mechanics into other genres.

### Conceptual change

In order to understand how playing *Citizen Science* affected conceptual understanding of the lake ecosystems, after consulting with the teacher we selected three students for pre and post interviews. The students were selected to represent a range of experiences and skill levels. Due to scheduling conflicts and absences, pre and post interviews were only collected for one student, identified as Amy. Amy is 12 years old and was chosen because she is talkative. As illustrated in this pre-interview exchange, Amy was well acquainted with

Madison area lakes and familiar with the physical manifestations of its changing ecosystem. The transcript has been edited for readability.

Interviewer: What do you know about the health of lake Mendota? Have you heard anything from jet skiing or using the lake about when or why it might be closed?

Amy: Yeah. Wasn't it closed a couple of years ago because there was too much algae in the water? And then sometimes it's a no wake zone in a certain area because the water levels are too high or too low. Mostly too high though.

Amy's response emanates from her direct experience of Lake Mendota. Amy has an awareness of algae levels and higher water levels, which is related to flood plain management, and has no direct relationship to algae (but is important for a jet skier). The interviewer probes her understanding of algae more deeply.

Interviewer: Can you say more about how algae is a problem?

Amy: Well, it just kinda clumps together everywhere, so it can be hard if you're gonna go like boating cause it could get stuck in the motor. That's happened to us actually quite a few times with jet skiing.

Amy responds in terms of her experience boating, so the interviewer guides her toward swimming to probe if that elicits a different response. Amy's response shows that she is aware of Lake Mendota's foul odor, but has little conception of the causes, how the Lake interacts with the broader watershed, the underlying chemical processes, nor how the lake might be made more habitable for human use.

Interviewer: Do you swim in the lake though?

Amy: Not really, no. Unless my brother throws me off?

I: Why don't you swim in the lake?

A: I don't really know why actually. It smells kinda bad sometimes. But, that's about it.

I: Do you know where the algae comes from? Why it happens?

A: Not really, no.

I: Do you know how one would go about fixing it?

A: Not entirely, no.

I: As far as the algae goes, can you say more about the problem? Is it a big problem with the lake? A little problem with the lake?

A: It can at times be a pretty big problem. It can depend on how much of it there is of course. I guess it could be bad for the health of the fish along with us in certain ways, because like I said, it just kinda clumps together so it could be bad if ingested with the fish or even like us, if we swallow too much water while swimming or something.

I: Why would that be bad?

A: Because um, it could be unhealthy in some way?

I: Any way in particular?

A: Um...

I: It's gross...

A: Yeah...

Amy's responses show that firsthand experience with Lake Mendota has led her to conclude that swimming in it is bad, because if too much were ingested, it could be dangerous (for humans or fish). Amy has a vague sense that algae could be poisonous, but no idea

where it comes from, what causes it, what could be done about it, or what its specific health effects are (other than being generally gross).

After playing *Citizen Science*, Amy's conceptual model of the lake watershed becomes more sophisticated. Amy uses the game's narrative as a scaffold for thinking through the causes of eutrophication, suggesting the role that narratives can play in mediating understanding. Amy had no difficulty explaining the basic game premise.

Interviewer: So what was the game about?

Amy: The game was about trying to help um, Lake Wingra reverse the pollution and stuff from the lake—to try to help it in the future. It was a like, euphoric lake or something?

I: Eutrophic.

A: Eutrophic, that's it! It was like a eutrophic lake, so you went back to the past and you were trying to reverse it from becoming a eutrophic lake so that you could swim in it and that it wouldn't be harmful.

Playing *Citizen Science* gave Amy a familiarity with the notion of eutrophic lakes, but her understanding of phosphorous did not become significantly more robust. In addition to introducing the notion of eutrophic lakes, *Citizen Science* contains an embedded model (see Fig. 2) that students (or teachers) could use to illustrate the concept of eutrophication. However students generally were confused by the longer explanations (even with the situated context of the lake investigation), and may have benefited from animations, images, or other explanations. Both teachers and students could have used the model to explore interacting variables and discovery (with some guidance) what conditions create eutrophication, but none did, suggesting the value of professional development in teaching with embedded models.

Mr. Taylor did augment the curriculum with readings and field trips to investigate Lake Wingra, an inland lake similar to Lake Mendota behind their school. Studying Lake Wingra was not something that the students did regularly, despite the existence of a boardwalk, outdoor center, and long history of scientific research on the lake (see Jan, 2009). In contrast, students recalled little from the readings (and perhaps ignored them), but valued the field trip.

Interviewer: What do you remember from the packets? What were they trying to teach?

S: Um, not really.

Because students appeared to be ignoring the packets, we continued this line of questioning. Amy responds with a relatively good description of a watershed that, triggered by her field trip to the lake incorporates her game experience.

Interviewer: (Laughter) Did you guys read them?

Amy: He passed them out, and he said I want you to read to page blahblahblah and so we did that. Then we talked it over, and then we went outside. We talked about the surrounding areas of Lake Wingra a little bit and its watershed.

I: What is a watershed?

A: It's like the areas um, surrounding the lake that are in close proximity that uh, that drain water and other like, stuff into the lake.

I: That's great. Why is it important?

A: Because it can help trigger, or it can help learn about what triggers the pollutants in the lake, like, for, I remember in the game, the farm was part

of its watershed, so all of like, the gross fertilizers and stuff like, drained from the farm into the lake and polluted it.

Amy provides a good explanation of how watersheds operate, which was one of the core learning goal (the health of a lake is determined by the watershed). She uses academic terminology such as pollutants, proximity, drained, and polluted in her response, all of which were not present in her pre-interview responses a few days later. In subsequent questions, the interviewer queried her knowledge about other quest-lines in *Citizen Science*, including rain gardens and zebra mussels. They were largely uninformed by her game experience, although she had prior understanding of zebra mussels from boating.

### Identity as a citizen scientist

A goal of *Citizen Science* is to create a bridging space for students to develop identities as citizens who care for their local lakes, so we looked for evidence of identity transformation toward a citizen scientist. Within the data, there was evidence from Amy of her increased interest, knowledge, skills, and values toward becoming a citizen scientist. This identity transformation was nascent, and drew heavily from her prior experience and associations with the lakes. Playing *Citizen Science* caused Amy to express concern about the lakes and regard the lake as important, but there was little evidence that she was going to take action tomorrow.

- Interviewer: How important do you think it is that we address these issues?  
 Amy: It can be pretty important. I remember the past part of the game was really carefree, and everything was all fine, and then like, we came back to the present and then there were all like, types of problems with the lake and things weren't working properly so in the future who knows what that could hold? Like it could just get grosser and... then that would be really gross.  
 I: Mmhm, so that could be a problem?  
 A: Yeah.  
 I: Do you think that the lakes are relatively healthy around here?  
 A: Um... no.  
 I: Why not?  
 A: Because just learning about when we went to the past or when we went back in the past, they were really like, clean and everything was perfectly fine and then we come here in the present and they were really gross and stuff I remember, in the game, so I guess things were, like, really healthy and clean with the lake, but now I'm not so sure that they are anymore.

Amy's notion of the past state of the lakes is relatively simplistic (even *Citizen Science* represents the history with more complexity; in fact, Lake Mendota was polluted with contaminants in the mid-twentieth century due to widespread dumping in the lakes). Playing *Citizen Science* disrupted (at least temporarily) her beliefs about the lake, supported her in questioning its health, bringing her to see it as a "designed" (as opposed to pre-determined) state.

*Citizen Science* was designed so that playing it might support players to question why the lake is currently unfit for human use, provide experiences of affecting change through direct and legislative action, and potentially direct students towards broader efforts and actions that are preventing local lakes from becoming eutrophic. Data suggests that playing *Citizen Science* drove this player to question the health of the lake, see its health as an

important problem, and as something that could be changed. There was little evidence for the game dramatically improving her self-efficacy in these areas, such as causing her to see herself as capable of changing the outcome for the lakes. Of course, asking such an identity transformation from a 4-day intervention may not be reasonable. However, this study provided some evidence for games' capacity to *disrupt* existing belief patterns rather than for systematically building new ones.

### Video games literacy and its implications

The studies reported in this paper ask how a digital game built using tropes and conventions from modern games might be used to help learners develop identities as citizen scientists within the domain of lake ecology. Our first expert-novice showed that games literacy was a strong mediating variable of understanding. This finding continued throughout the classroom implementation, with the teacher's move to hand over control to the class during the playing of the game enabling gaming cultures to emerge. The teacher devised a number of novel pedagogies such as field trips to investigate the local watershed in response to the unit. Examining students' responses, we found evidence for the most desirable learning occurring through these activities that were reinforced via the curriculum. By "desirable learning," we refer back to our earlier discussion of hybridized identity. The primary goal in designing *Citizen Science* was not to create a system that teaches students lake science content more efficiently, but rather to provide avatar identities that challenge player identities and in so doing, encourage the construction of hybrid identities that relate to real needs in their community. Though the reading packet provided included information that was relevant to the lakes, it did not provide players with an experience that was easily related to their field trip whereas the game may have. Analysis of surveys reveals that *Citizen Science* engaged students, particularly through its most "gamelike" features. However, identity transformation was far from complete.

### Games literacy: A +1/−1 double-edged sword

Our expert novice study and subsequent classroom implementation corroborate earlier studies, which argue for the importance of games literacy (see Squire 2006). Building on diSessa's notions of scientific literacy, games have their own material, symbolic, and social systems for conveying meanings, and those participants experienced with game worlds' physical materials, symbolic systems, and social patterns (e.g. asking for help in complicated adventure games) navigated the system fluidly, enjoyed the experience and made new meanings from the experience congruent with the designers' goals. Less experienced players—even those with deep domain-related expertise that one might expect to scaffold them in reading game texts (including multi-modal texts such as maps and graphs), had difficulty using the game's embedded model and interpreting the game's narrative.

In light of recent trends to "gamify" social structures, we argue that research examining the importance of games literacy is essential for creating and distributing games that do not reify and perpetuate current social inequities. While games can provide local context and civic-mindedness to play via narrative (e.g. Jan 2008), limitations that accompany the meaning-making processes associated with game play may interfere with presenting educational content or identities to players. That is, differences in player backgrounds contribute to their interpretation of games (DeVane and Squire 2008) and (un)familiarity

with genre conventions may exacerbate this interpretive process. Though video game play is widespread amongst teenage Americans, demographics are not evenly distributed across differing game genres (Ito et al. 2009).

Indeed, if games literacy is a mediating variable in learning through game play, educators seeking to infer what players know through simply assessing in-game interactions may never be to validate these measures using classic validation theory, which requires gathering evidence to show that the desired construct (in this case lake ecology) is being measured (Messick 1993). In creating a nomological net of evidence to support claims about learning, one would gather many forms of evidence, including construct-related evidence (evidence that the content is indeed from the desired domain) and criterion-related evidence (evidence that experts perform better than novices on the tasks). In games (as in assessment in general), educators most often provide construct related evidence for the validity of assertions based on observations (e.g. this content is really lake ecology), and much less frequently gather compelling criterion related evidence for the validity of assertions on students' learning (exposing their assessment instruments to experts and novices alike).

This study suggests that educators making inferences of students' knowledge based on in-game experiences face challenges. By way of analogy, imagine an expert on lake ecology fluent in oral language but not in written symbolic systems attempting to take a test on lake ecology. Despite robust understandings of inland lakes, our expert might perform poorly. Educators seeking to find criterion-related evidence for the validity of games as assessment tools might face a similar conundrum: Instead of measuring only knowledge of lake ecology, they are also measuring knowledge of game symbol systems.

The nature of games literacy as a mediating variable may be particularly important in games like *Citizen Science* in which the game *itself* teaches the player how to play it through carefully structured interactions. Whereas our experts (and teachers) largely did not learn to play *Citizen Science* in the time provided, younger players did so with little trouble. The interface and narrative elements that confused experts drew in younger players. Further, in longer interviews, players drew on these elements (including recollections of specific characters) as they interpreted their game play experience.

In fact, when designers embraced adventure mechanics most explicitly particularly through *memorable moments* consisting of very difficult puzzles, hidden areas, and in-jokes, players responded the most strongly and learning was most likely to transpire. Much like adventure games themselves, these elements were not universally loved nor admired. However, elements such as difficult puzzles and hidden areas generated the most discussion in contexts where knowledge was collected and shared. Similarly, unusual characters or plot twists were frequently mentioned in post responses and were hooks around which players could build understandings.

Educational game designers may soon face a quandary: To what extent should they design games that honors genre conventions to thus (potentially) produce learning, as opposed to using traditional pedagogical methods, like evidence centered or backwards design, which reproduce existing practices such as placing pedagogy first, that, although they might produce reliable results, may also fail to take full advantage of the medium. This study persuades our design team to continue exploring novel approaches to educational game design, which not only draw upon established genre conventions, but also push them even further to attempt to design compelling, transformative learning environments.

## Learning in games

These two studies provide limited, but encouraging evidence for educational game design that seeks to build game experiences around one or two big ideas (such as analyzing lake ecology through its watershed), and that situates learning within compelling challenges in which players can affect the world. Teachers and students perceived the experience of *Citizen Science* as educational. In the recorded pre post interview, we observed changes in language use, vocabulary, and knowledge of the lakes.

The pre–post interview also highlighted the importance of not isolating game experience from other experiences, but creating productive interplay among them. Combining game play experiences with field experiences yielded the productive discussions about the lake and its watershed. For example, in the post interview presented earlier, the respondent blended these two experiences together to such an extent that she erroneously referred to *Citizen Science* being about Lake Wingra, a local lake that the students had visited in the field experiences. Given that she grew up near Madison lakes, jet skied on them regularly, and had direct experience of the manifestations of the ecological issues surrounding them (algae in props), it was somewhat disconcerting that she had little understanding of its causes. Playing *Citizen Science*, particularly when coupled with a field experience enabled her to produce a much more robust explanation for the causes of these issues.

One of our current goals is to collaborate with Mr. Taylor and other teachers to create several “model” curricula that they might use in their classrooms. We envision students playing *Citizen Science* then going out and studying watersheds in their own communities. They might gather data in a similar way to the methods they used in *Citizen Science*, creating graphs, charts, or other representations to visualize data and make arguments about the lake. We also envision them writing letters to editors (similar to how players of our mobile games have, see Squire 2011), or engaging in other citizen science activities as appropriate. Although there are many ways one might use game-based curricula, we envision *Citizen Science* playing something like an advanced organizer role, introducing basic, foundational concepts, enlisting players’ identities as citizen scientists, and illustrating how these activities might be conducted. We saw little evidence from these studies that playing *Citizen Science* alone (in its current form) would lead to such dramatic identity transformations.

A final direction that studies of games such as *Citizen Science* could take is in providing more robust assessments testing understandings. In this implementation, providing any further assessments was not feasible given time constraints and other local factors (always an issue in classroom-based research). However, we envision near transfer tasks involving plotting the study of a local river watershed, or further transfer tasks in which players investigate deforestation or desertification. It may be that games are most successful in shaping students toward raising productive questions about such environments rather than communicating definitive answers.

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