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Breaking SPORE: Building Instructional Value in Science Education using a Commercial, Off-the Shelf Game

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ABSTRACT

This investigation explored an alternative method of technology integration and ways to enable educators to judiciously use a wider range of games in their classrooms. Although many games have been created with educational objectives in mind (e.g., Quest Atlantis, Immune Attack, Democracy), proportionally fewer games and simulations are linked to scientific content and standards. More importantly, wildly popular and widely available entertainment-based games with educational components (i.e., edutainment) do not necessarily promote scientific understanding. Generally, the purpose of games is entertainment. However, issues may arise if they are marketed as promoting or having a strong basis in content. In this study, we examine the simulation game *Spore*, which exhibits flawed scientific assumptions and may promote numerous misconceptions if used "as is" with students. We examine how a simple pedagogical adjustment to in a middle school science class may overcome the existing and designed limitations while yielding learning benefits. Specifically, we observe *Spore*'s influence on students' conceptual understanding of natural selection when compared to a control group. The findings contribute to a growing body of literature that provides teachers with alternative methods for judicious technology integration, particularly with respect to the affordances of games and simulations like *Spore*.

Keywords: *video games, science education, technology integration, evolution, Spore*

INTRODUCTION

In education, practitioners are individually responsible for numerous decisions that directly impact the context and delivery of instruction. With respect to technology, researchers have argued that judicious integration relies of a number of factors (Archambault & Crippen, 2009; Colbert et al., 2008; Cuban, 2000; Schrader, 2008). Like any other technology, video games require careful consideration if educators seek to mindfully and successfully integrate the tools with their instruction. Researchers have explored numerous innovative methods and instructional approaches to using video games in education, such as an immersive context for learning (e.g., Quest Atlantis, Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005), a tool for delivering information (e.g., FunBrain, Pearson Education Inc., 2015), or a topic to provide context for a related task (e.g., computer programming, Thomas, Ge, & Greene, 2011). Generally, these applications and examples are limited to their respective contexts. It is up to teachers to decide whether or not they will introduce games into their instruction, as well as the degree to which and manner in which games are implemented. Games may be used as a stand-alone instruction (e.g., artificial intelligence or instructional content) or they may serve some overarching pedagogical approach (e.g., problem-based learning and GlobalEd, Brown, Lawless, & Boyer, 2013). These decisions are based on the

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classroom context, but are undeniably influenced by the affordances and characteristics of the games themselves.

In terms of the goals that drive the design of games, industry professionals are commonly interested in creating entertaining games that provide a significant and often sustainable source of revenue (e.g., subscription models). By contrast, educators and researchers are committed to understanding and leveraging the educational attributes of games. These two goals are not always aligned. While researchers work to find educational properties of almost any genre of game (e.g., Ching, 2012; Gee, 2003; 2007; Schrader & McCreery, 2007; Squire, 2006; 2008; Steinkuehler, 2006; Young, Schrader, & Zheng, 2006), developers do not necessarily leverage the current knowledge base when creating games. The difference between developers' and educators' core goals may be further exacerbated by the complexities of technology integration in classrooms. Even games that fall in the educational-entertainment category (i.e., edutainment) may exhibit characteristics that are not directly consistent with content learning.

Even though games may not align with curricular and content objectives in a direct and meaningful way, there are at least to factors that compel educators to continue investigating judicious integration strategies. First, games are tremendously popular. Whether or not one cites revenue (Statista, 2015), player base and proportion of play (Statista, 2015), or self-reported habits of play (Pew Internet and American Life, 2008), the evidence supports the pervasiveness of games in modern, global culture. It follows that educators seek activities that students find relevant, fun, and meaningful. Second, researchers and supporters are quite vocal in their endorsement of games and the discussion of positive, educative potential for games in education is well established (e.g., Gee, 2003; 2007; Steinkuehler, Squire, & Barab, 2012; Young et al., 2012). More importantly, the topic regularly appears in mainstream media, where it is far more likely to be consumed by teachers and educators (e.g., Cortez, 2015; Sparks, 2014; Talbot, 2015). Collectively, the popularity of games and their frequent reference in literature may persuade teachers to adopt games-based learning tools and simulations directly off the shelf.

Although teachers and educators may consume mainstream media (and the highlights about games), they do not necessarily have the time or skill to peruse research literature in an effort to discern best practices. Further, there is little general and actionable information about effective strategies or approaches to utilizing games in classrooms. Although there is a growing body of literature that highlights several numerous and beneficial affordances of games, as well as the contexts in which those traits are most beneficial (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Young et al., 2012), existing research is situational and highly specific (Plass et al., 2013). In articles that describe integration projects, there is often insufficient detail and evidence to make appropriate instructional decisions (e.g., Angelone, 2010).

Given that there is a large market for video games, developers may rush to create educational titles so they may attempt to capitalize on market trends without careful attention to content standards and research findings. As a result, arguments in the literature acclaiming the virtues of games and findings that document best practices in game design may not align with the affordances present in contemporary video games, particularly those designed for commercial purposes. However, companies are not necessarily motivated to create games for learning; they create them for profit and, with rare exception, for entertainment. In extreme cases, games designed and promoted to be content focused may actually lead to undesired consequences. For example, *Spore* is a game designed around the concept of evolution, but play is likely to reinforce misconceptions, rather than promote scientific understanding (Bean, Sinatra, & Schrader, 2010; Schrader, Lawless, & Deniz, 2010).

Fortunately, many of these issues can be resolved if researchers and educators continue to shift attention from discourse extolling the virtues of educational gaming and toward a more critical, thoughtful approach of incorporating games in science education (Angelone, 2010; Bean et al., 2010; Schrader et al., 2010). Said another way, practitioners' must be aware of a tool's characteristics (i.e., strengths and weaknesses) and follow appropriate pedagogical practices to ensure judicious integration of games. As a result, this study adds to the growing body of research that has begun to outline the manner in which games and their affordances may be meaningfully incorporated into curricula, especially science content (Bean et al., 2010; Ching, 2012; Schrader et al., 2010). Specifically, this study focuses on the ways to maximize the impact of *Spore* the study of biological evolution. Although there is ample evidence that there are many factors in teaching biological evolution (e.g., religiosity, disposition toward acceptance, etc.), a curricular manipulation may help promote students' understanding of natural selection while addressing several of *Spore*'s weaknesses as a learning tool.

REVIEW OF THE LITERATURE

Games in education: Potential and challenges

Video games have been a part of social culture in the United States for more than 30 years. By 2000, improvements to information computer technologies allowed massively multiplayer online games to become part of our collective, global culture. Today, the pervasive integration of video games into popular culture is highly visible and apparent. Video games have inspired movies (e.g., Tomb Raider, Final Fantasy, Doom), business opportunities (e.g., combination video game bars, gaming centers, restaurants), and international competitions (e.g., League of Legends, StarCraft). From an educational perspective, researchers have been interested in video games for nearly as long as they have been on the market (see Bowman, 1982). The literature is not only replete with warnings about dangers (e.g., gender bias, aggression, or addiction) but also with findings about benefits (e.g., content, process, social skills, or game skills) (Connolly et al., 2012; Plass et al., 2013; Young et al., 2012). In terms of benefits for science, researchers have examined and demonstrated the value of collaboration and social responsibility within immersive spaces like Quest Atlantis and River City as contexts for learning (Barab & Dede, 2007; Barab et al., 2005). However, like most examples, these implementations are very content and context specific. As a result, these environments do not generalize well as a framework for integration. Without additional insight, it would be difficult for most teachers to translate Quest Atlantis or River City to their classrooms and current science standards.

Unfortunately, others later commented on the key differences between the content in *Spore* and accepted scientific understanding (Bean et al., 2010). More importantly, researchers have argued that *Spore* may promote or reinforce scientific misconceptions if treated as a stand-alone or content replacement. Specifically, the underlying mechanics and algorithms in *Spore* trend toward three biases: the essentialist (biological forms possess an immutable essence), teleological (assignment of purpose to living things and/or parts of living things that may not be purposeful), and intentionality (assumption that events are caused by an intelligent agent) biases (Bean et al., 2010; Evans 2001; Kelemen, 1999; Poling & Evans, 2002). Collectively, these biases are a major concern for educators and correspond to a significant line of inquiry in science education research (Sinatra, Brem, & Evans, 2008).

Although some might suggest that merely playing a game does not guarantee learning, Turkle (2009) warned the research community about this very issue. Specifically, immersive play or experience in a simulation has the potential to generalize to real life. In one example, Turkle indicated that a gamer that played Sim City concluded that raising taxes always results in riots. The player's inference arose from directly and indirectly experiencing the mechanisms that the programmers built into the game. This may have been due to a programmer's bias or a general desire to simplify game rules for enjoyment purposes. Regardless, Turkle maintains that players discern the models and relationships from the games they play. If the underlying rules do not align with curricular objectives or accepted understanding, then direct experience and play is not a desirable integration approach. At a minimum, there is a need for students to understand the models they experience, as well as when those models are appropriate and when they are not (Angelone, 2008; Jonassen, 2006).

SPORE and Biological Misconceptions

Teaching biological evolution is unlike any other topic in science. It is wrought with the potential for misconceptions and misinterpretations. Personal biases may lead to inappropriate conclusions that do not align with scientific understanding. More importantly, few topics are surrounded by such controversy or have become the target of public interest. The principles and ideas associated with Darwinian evolution are sometimes at odds with personal, social, or religious beliefs. In the case of *Spore*, researchers have argued that there are opportunities to reinforce the essentialist, teleological, and intentionality constraints (Bean et al., 2010; Sinatra, et al., 2008). Separately, each bias could present an obstacle for instruction using simulations; *Spore* exhibits tendencies toward all three.

According to an essentialist view, organisms' traits and qualities are intractable and cannot change. Specifically, those adhering to this bias are unable to accept the development of a species over time and across numerous generations. Within the game, evolution occurs within individuals and their offspring, rather than populations. Although this decision may have been necessary, it does not address concepts like statistically large numbers, geologic time (i.e., billions of years), or genetic variation. Rather, *Spore* affords players the opportunity to completely redesign their creature at will. Although this practice does not directly contradict evolution, it masks the accepted mechanisms (e.g., variation, randomness, the process of natural selection, and geologic time) and promoting non-scientific views associated with the essentialist bias.

The second bias relates to goal orientation. By design, video games like *Spore* are built around goals. Players adopt those goals and designers create systems to allow players to pursue those goals. In *Spore*, designers have created a form of currency or reward for achieving some of the smaller objectives: DNA points. Similarly, defeating various organisms or objectives may unlock different generic parts of an organism, each of which has different attributes (e.g., stronger or faster limbs, wings for flight, night vision eyes). If a player collects enough DNA points and has unlocked the appropriate parts, they can build their desired organism. For example, a player might be able to remodel their quadruped's front legs with wings so that it can fly. Although DNA point accumulation and organism redesign may be fun for the player, the process also suggests that evolution is goal-directed. However, the idea that organisms change their characteristics to adapt to (and conquer) their environments is more accurately known as the teleological bias and is in direct conflict with Darwinian views of evolution (Kuhn, 1970; Sinatra, et al., 2008).

In the process of pursuing the game goals, a third misconception becomes evident: the intentionality bias. After players have acquired sufficient generic parts and DNA points, they are able to decide how to build their organism. Players maintain complete control over their organism's design, function, and capabilities. If they see an obstacle, they may manipulate their organism and make specific changes in order to overcome that obstacle. Players even make a decision on what types of food and resources their organisms consume, which results in an herbivore, carnivore, or omnivorous creature. While deciding how their creatures interact with the environment at a fundamental level, *Spore* diminishes any notion of randomness, natural selection, and evolution to a misconception of control by some intelligent agent. More importantly, *Spore* introduces a notion that someone or something controls how an organism evolves, such as the organism itself.

Because of its potential to reinforce these misconceptions and the critical nature of these biases, it may be problematic to use *Spore* as an educational game right out of the box. Fortunately, the literature also suggests a few solutions and ways teachers can modify the broad educational context to promote learning. For example, Jonassen (2006) suggested that a crucial step towards conceptual understanding and change involves challenging existing models. Similarly, Angelone (2010) suggested that students might benefit from blogging or writing about the differences between the game and accepted understanding of biological evolution.

As a result, this study addressed the general question of whether or not it is possible to use a commercial, off the shelf game that has been created for entertainment purposes as a simulation that promotes scientific understanding. In the process, *Spore* was examined in terms of strengths and weaknesses and a curricular/pedagogical modification was identified. For simplicity, one key variable associated with students' understanding of biological evolution was evaluated, conceptual understanding of natural selection. This measure was used to ascertain whether or not a minor shift in the encapsulating pedagogy provided students with sufficient learning opportunities to comprehend natural selection. Student essays were also evaluated to support these inferences. The following specific research questions were generated:

1. Does a pedagogical modification to video games in education impact students' conceptual understanding of natural selection?
2. Do students' essay responses to playing a video game support these differences, should they exist?

METHODS AND PROCEDURES

Game description

At the time of this writing, *Spore* is a venerable game, having been released in 2009. Although there have been numerous educational tools and integration examples since its publication, *Spore* was selected because it for three reasons. First, *Spore* was created by Will Wright and situated upon a tradition of popular games like Sim City (Electronic Arts, 2008). This connection to popular culture may correspond to increased visibility and student interest, albeit novel, in playing the game. Second, *Spore* appears to address educational content and objectives, at least superficially. Specifically, the original marketing campaign described *Spore* as an "experience in evolution," linking it to middle school Science standards (Electronic Arts, 2008; Wright, 2008). Shortly after release, there had already been interest by researchers and educators in terms of *Spore*'s potential for classroom integration (Angelone, 2010). However, the third reason that *Spore* was selected was due to several content issues. Specifically, the underlying design of the game creates opportunities to reinforce or establish some of the most difficult and pervasive scientific misconceptions associated with Biological Evolution. Considering each of these reasons, *Spore* represents software that would be compelling for many teachers, while presenting serious content challenges and risks if used as a stand-alone tool. Ultimately, teachers who took a comprehensive look at *Spore* would probably dismiss it and select an alternative. As such, *Spore* serves as a model at least one alternative integration approach that may apply more broadly to all commercial off the shelf (COTS) video games.

In terms of play, *Spore* is a complex, graphically rich video game that allows players to control the actions of a creature through several stages of biological, cognitive, and social development. Initially, players control a single celled organism that "swims" through its environment. During the cell stage, the player selects the major attributes of the cell, including size and diet (i.e., carnivore or herbivore). Players quickly learn that some things in the environment are harmful or beneficial to the development of their creature. The player may elect to have their cell eat plant or animal matter as their cell becomes more complex. Throughout, players unlock parts (e.g., flagella, a proboscis, eyes) that enhance their cell's capabilities. As a result, the player may integrate these newly acquired parts to create a cell that can attack all other cells or flee them using speed. Ultimately, the goal of this stage is to accumulate sufficient complexity, which is measured in DNA points, so the organism may "evolve" legs and leave the liquid environment.

On land, the primary activity returns to eating and collecting genetic material. However, the creature can also befriend other creatures using social skills (e.g., singing, dancing, posing). By contrast, the player can also cause the creature to attack others in the environment and attempt to dominate them via aggression (e.g., biting, striking, spitting). Again, DNA points are awarded either for eliminating or befriending a different species and once sufficient DNA points have been accumulated, the player can use parts to alter their creature. This is accomplished via sexual reproduction, a process that involves calling a mate, entering the reproduction screen, and manipulating creature's characteristics (e.g., number of limbs, type of mouth, eyes, etc.). Upon leaving this screen, offspring are immediately produced and reflect all of the changes made by the player.

Once the creature has advanced a pre-defined number of times, it enters the tribal phase. At this point, it no longer evolves on a biological level. The tribal phase and two subsequent phases involve the development of socialization skills in a tribe, a civilization, and an intergalactic empire. Players create buildings, manipulate resources, and control space ships as their creature continues to advance. Similarly, the remainder of game play involves interacting with other species and civilizations so the player's civilization can advance. The final objective in the game is to defeat an evil empire (i.e., Grox) and conquer/control the known galaxy. Although all five stages of *Spore* are entertaining, the first two phases were deemed relevant to this research by virtue of their relationship to Darwinian evolution. As a result, these stages will serve as the focus of discussion.

Classroom and research context

Over the course of a month that ended in March 2011, four sections of 8th grade students from a private school in the Western United States the topic of biological evolution. Class sizes ranged from 8 to 20 students. The same instructor taught all students. Each student participated in various activities, readings, and labs designed to facilitate their understanding of basic principles associated with Darwinian evolution (e.g., deep time, heredity, competition, natural selection, speciation, role of genetic mutation). Each class lasted 50 minutes and technology was an integral part of the daily activities. Each student had access to a netbook computer and login that provided access to assignments, reports, homework, and other relevant materials. Although it was not required, the curriculum loosely accorded to the national science content standards.

During the mid-point of the unit on evolution and prior to data collection, all participants were given an opportunity to play *Spore* for 30 minutes. Researchers have indicated that 30 minutes is a minimum timeframe for training and to acclimate to new technology (McCreery, Schrader, & Krach, 2011; Schrader, Archambault, & OhYoung, 2011). During data collection, students played *Spore* a second time for approximately 40 minutes. During this session, participants were randomly assigned to two groups. The control group played *Spore* with no additional conditions. This was thought to be similar to a teacher merely asking students to play the game as an off the shelf tool without any modifications. The experimental group also played *Spore* but was asked to log issues with the ways in which *Spore* exhibited inconsistencies with the content they had learned. Upon completion, students in each group were asked to complete an argument associated with either *Spore* (treatment) or evolution in general (control).

Participants

For this study, participants were 56 8thth grade students (47% female, 53% male) from a private school in Western United States. Students were from four separate sections taught by the same instructor. The ethnic composition of participants in this study was 79.6 % White, 11.9% Asian, 5.1% African American, and 3.4% Hispanic. Participants in this school were chosen because of convenience. Fifty percent of the overall student population was on a scholarship.

Instruments and data collection

Participants' understanding of evolutionary theory was measured through the Conceptual Inventory of Natural Selection (CINS). This scale consists of 20 multiple-choice questions and was developed by Anderson and Fisher to measure understanding of natural selection (2002). Due to course relevance, only the first 13 questions in CINS were used in this study. A cumulative score was given to each participant based on the number of correct responses. A score of 13 represented a very high degree of understanding of natural selection, while a score of 0 indicated no understanding of natural selection.

After playing *Spore*, students were provided with an essay prompt that was intended to document their understanding of biological evolution. Students who were assigned to the control group were asked to develop an argument in support or opposition of the statement "evolution is a well-supported theory explaining how all organisms have changed throughout history." During their arguments, they were asked to consider the following ideas: the major principles, evidence that

organisms change over time, criticisms of evolution, and major mechanisms of the theory.
Similarly, students assigned to the experimental condition were asked to develop an argument in support or opposition of the statement "*Spore* is a simulation type of game that will help students understand Darwinian evolution." They were asked to consider: the major principles evident in *Spore*, the software's strengths and/or weaknesses, whether or not it is an accurate representation of what they know and why, and how they might modify the game.

Participants in both groups completed the CINS survey before and after the final play session (50 minutes). Students in both groups were given their prompts prior to playing *Spore* and were allowed to take notes. Students in the experimental condition were prompted to take notes about their game play as part of the augmented pedagogy.

Data analysis

To address the research question, the data were analyzed using Statistical Package for the Social Science (SPSS 21.0). Means, standard deviations, maximum and minimum were calculated and assumptions of normality of sampling distributions and linearity were upheld. To determine whether evolution instruction influences on students' understanding and acceptance of evolutionary theory, an independent-samples t-tests (equal variances not assumed) was performed using students' scores on the CINS following gameplay. A total of 32 students were randomly assigned to the experimental condition and 26 were assigned to the control condition.

RESULTS

Research question one

Using an alpha of .05, results indicate that there was a significant difference between the experimental and control groups, $t\ (54) = 2.328$, $p = .024$. A non-parametric Mann-Whitney U test, $p = .02$, confirmed parametric results. Follow up analysis indicated that the experimental group performed better than the control group in terms of their conceptual understanding of natural selection (CINS).

Research question two

As one might expect after a month long unit on Darwinian evolution, there was evidence of understanding in both the experimental and control groups. Collectively, students referred to concepts like inheritance, natural selection, mutation, and adaptation. They also acknowledged criticisms of evolutionary theory, including religious criticisms and the complexity of the theory. According to one student, due to "religion, many people believe that god created all creatures…"

In their arguments, students related considerable amounts of evidence, including fossil records and the Law of Superposition. One student even attempted to resolve some of the discrepancies between evidence and belief, stating that:

"There is no way to know for sure whether evolution occurred with the tools that we have today. Without complete evidence that gives no doubt of the occurrence of evolution, some people will still never believe, and that is because they believe the ideas of their religion. Religion and evolution both have valid points, but more people believe religion because it has been studied longer. Although religion has been around longer, evolution has more evidence pointing towards it."
Although students' exhibited broad understanding of the principles covered throughout the course, essays from students in the experimental group were considerably more focused and provided more detail about the principles. More importantly, students demonstrate that they have considered important principles to a great depth. It seems that the activity has prompted careful consideration of the cued topics. One response demonstrates this clearly when a student described the shortcomings of the game:

"…in this game there are more false representations than accurate representations. SPORE bases mutation and variation on the personal whim of the creator. Sexual selection is not represented at all accept by a click of a button (the mating call). Natural selection is again like mutation and variation at the whim of the creator and cell genetics is not based on heredity or pass generations. As a game, SPORE is fantastic and really fun I have to admit, but as a comparison to evolution it's a phony."

Generally, the arguments were also much better developed. This latter finding was somewhat surprising, given that argumentation is a difficult skill to master (Nussbaum, in press). However, students were asked to take notes in a T-chart. They copied the merits of *Spore* as well as its issues. Although unintended, this approach may have provided students with specific warrants and rebuttals in their arguments (Toulmin, 1969) and scaffolded their efforts.

Limitations

The current research has some limitations in terms of its ability to generalize the results and the overall design. First, these results generalize only to schools and environments that closely resemble the conditions described in this study. Specifically, participants in this study were selected from a private school in the Western United States. Although half of these students were on scholarship, they enjoyed regular exposure to technology and games, both at home and in their classrooms. These circumstances do not necessarily describe the average classroom. In terms of design, every effort was made to equate the conditions with the exception of the prompt and activity. However, it is not clear to what degree the pre-game question influenced the outcomes. For example, the question and activity may have served as an advanced organizer that eliminated or limited additional cognitive load. Subsequently, this relief may have enabled students to focus on the question at hand while playing the game. Additional research would be necessary to determine what role the question and essay activity engaged higher order thinking.

IMPLICATIONS AND CONCLUSIONS

Although the findings reported here are somewhat limited, this study builds upon a growing body of literature that highlights the potential of games in education, as well as the ways in which games might be used as instructional tools (Young et al., 2012). In this study, results suggest that critiquing the underlying models of *Spore* and using the game as a platform to stimulate that discussion has an impact on learning outcomes. Although the quantitative results are only linked to natural selection, they indicate that this pedagogical adjustment has a positive impact on understanding. The essay responses provided additional insight about the nature of the activity. In particular, it seems evident that all students learned from the instruction. However, the game play session coupled with a carefully designed essay task seems to have greater impact on students as they consider the subtle aspects of Darwinian evolution. Students in the experimental condition generally expressed more detailed and related ideas when providing criticisms of *Spore*. Lastly, this activity had the surprising benefit of facilitating the development and articulation of warrants and rebuttals.

These findings have many potential implications for teachers and the overarching pedagogies associated with integrating video games in education. Specifically, games and simulations have their place in science instruction but they do not necessarily need to be “perfect” in a curricular or scientific sense. There have been three popular methods for integrating video games for the purpose of learning (Van Eck, 2006). First, students may act as game developers to learn either programming or the content associated with the game (e.g., Thomas et al., 2011). This approach is often used in computer science and related areas. Second, teachers may employ video games that have been designed for the purpose of learning with clear educational objectives in mind. In this case, educational content is embedded within an engaging gaming environment. A third method leverages commercial, off the shelf games (COTS) in creative ways to bridge curricular objectives with available software. Although *Spore* is old by video game standards, it serves as a good example of a game that fits this latter category and addresses evolution topics and principles in a broad and somewhat inaccurate manner.

This research confirms that judicious technology integration requires planning and preparation. Although teachers are undoubtedly aware of this, these findings provide an additional method to bring tools into the classroom, whether or not they are directly linked to curricular and content objectives. Because curricular alignment is rare, teachers are advised to examine the content and objectives first, and the technology second. For this purpose, teachers may find “Teaching about Evolution and the Nature of Science” (National

Academy of Sciences, 1998) and "Understanding Evolution: Your one-stop source for information on evolution" (http://evolution.berkeley.edu/) to be valuable content resources when teaching biological evolution. However, the integration of technology involves a few additional steps. Teachers are encouraged to explore the tools carefully and thoroughly. In this step, teachers strategically seek and identify the tool's characteristics, strengths, and weaknesses, as well as the potential links among those affordances with curricular objectives. There are numerous texts and online resources that outline how this should be approached (e.g., http://www.edutopia.org/technology-integration-guide-implementation).

In the case of *Spore*, taking the time to play the game in the context of content objectives revealed the weaknesses in terms of scientific misconceptions. However, it was also clear that those misconceptions could come into direct focus by having students criticize how the game was designed. This process allowed students to use what they have learned in an authentic way. Considering the integration process more broadly, it is clear that no simulation or game is complete and allowing students the opportunity to critique the games in question may be valuable, regardless of content area. This aligns with messages from various researchers (see Angelone, 2010; Bean et al., 2010; Schrader et al., 2010). More importantly, this advice empowers teachers to mindfully and purposefully integrate games into their classes.

This research highlights one example of a successful classroom adjustment. Specifically, the study applied Jonassen's (2006) view that deconstructing a model in light of its flaws is a valid method to promote conceptual understanding. However, teachers' success with video games, simulations, and similar technologies may rely on many more factors. For example, this study involved the: a) ability to detect flaws in a system, b) ability to adapt and align the tool to learning objectives, and c) understanding of alternative pedagogies. Judicious integration of any technology (e.g., a game or simulation) depends upon the interaction among practitioners' knowledge of tools, knowledge of content, and knowledge of pedagogy (Archambault & Crippen, 2009; Colbert et al., 2008). Although this can be a challenge, teachers may gain better chances if they follow a few guidelines as suggested here and reported elsewhere. Collectively, these prerequisites may prove to be difficult, or even impossible, for many teachers to address. However, we are encouraged by these data; they reveal that the educational power of video games lies in the hands of teachers rather than software developers.

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