Cellvival! The Design and Evaluation of a Game to Teach Biology

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Introduction

Science labs and educational digital games can be very useful tools for dealing with the inherent challenges of science education. Among these, one key challenge is lack of engagement or motivation (Cordova & Lepper, 1996; Hidi & Harackiewicz, 2000; Kuh, 2001; Krapp, 2002; Carini, Kuh, and Klein, 2006) and another is dealing with naïve theories students have formed prior to instruction that affect how they interpret new information (Carey, 1989; Carey & Wiser, 1989; Gopnik, Meltzoff, Kuhl, 1995). There is also the general difficulty of getting one to change their current theory in more than a superficial way (Kuhn, 1962; Wiser and Carey, 1983; Carey, 1985; Vosniadou & Brewer, 1987; Ozdemir & Clark, 2007). Finally, there is the finding that students will have better outcomes with certain epistemologies (Songer & Linn, 2001), which means an educator must be mindful of tacit epistemology of their curricula and behavior to pursue optimal educational outcomes. While daunting, these challenges are not insurmountable.

When lab modules are well designed and integrated into a larger lesson, generally in a form similar to the "learning cycle" (Lawson, 1958; Karplus & Thier, 1967; Guzzeti et al., 1993), they can be quite effective at facilitating theory change and greater understanding (Hofstein & Lunetta, 2004). However, there are practical limitations to the use of conventional labs that renders some crucial content either too expensive, difficult, or otherwise impractical to demonstrate in the classroom. This is particularly true of phenomena that occur over long period of time or at large scale, such as speciation and relativity.

Well designed educational digital games are uniquely suited to cover these topics (Gee, 2003; Ryan, Rigby, Przybylski, 2006; Barab et al. 2009). The artificial worlds of video games can be designed to allow demonstrations and exploration that would be impossible in the physical world, but that can demonstrate concepts and provide information relevant to physical world (Shaffer, Squire, Halverson, Gee, 2005; Squire, 2006), and provide many other benefits. The experiential nature of games, and the ability to repeatedly test models and refine concepts and skills can lead to deeper, intuitive understanding.

In this project, these two tools are combined; the educational impact of a game about evolutionary concepts, *Cellvival!* situated within a lab-like module, was evaluated and compared to the impact of typical instruction on the topic. The module was self-contained and included lesson plans for the teacher and handouts and homework for the students, to facilitate instruction and effective use of the game.

Project Goals

The game *Cellvival!* was developed as part of a research project to be used in high school biology classes from intro to AP levels. The primary goals included:

- Design a game that communicates evolutionary concepts through the mechanics and gameplay. Meaningful choices and the dynamics that arise from them within the game should correspond to behaviors and dynamics that arise in real world systems.
- Increase student engagement and interest.
- Produce a valuable educational tool for teachers; one that would be easy to use in class, and higher impact than other approaches.

Research questions:

- How do the gains from the *Cellvival!* module compare to those of the standard lesson (both in terms of superficial content knowledge and deeper understanding of concepts)?
- Does the *Cellvival!* module facilitate deeper or more transferable understanding of the topic? A better ability to reason evolutionarily?

Background

ASSET

Cellvival! was developed in partnership with the ASSET program (Assisting Secondary Science Education with *Tetrahymena*), an NIH funded SEPA outreach program. ASSET is a collaboration of researchers and former teachers that develops high school biology lab modules that use a single-celled protist called *Tetrahymena* as a model organism. *Tetrahymena* has a number of properties that make it well suited to the program's needs as it is easy to cultivate, non-pathogenic, widespread in nature, and has a number of qualities that are interesting to high schoolers. For example, it has a cannabalistic variant, seven sexes, and can reproduce sexually or asexually. The ASSET program has a number of modules available, on topics from phagocytosis to population curves, that they train teachers to use and distribute to teachers in schools across the country.

The ASSET program was interested in developing video game content that would both engage students in new ways and reinforce other modules in their curriculum. We met and agreed on the project goals, then I developed the game's concept, design (mechanics and interface), and art direction.

Student involvement

Following initial design work, undergraduate programmers and artists were involved in the production and ongoing development of the game. High school students were also involved in the development process, particularly in creating art and music assets. This allowed the project to provide value before being ready for science classrooms, as students got some experience with the process of game development and the plethora of disciplines (art, biology, education, music, psychology, computer science) involved in educational game production.

Evolution education

While central to much of biology, evolution can be a controversial topic, and some work has been done on resistance to learning evolutionary reasoning and ideas (Evans, 2001). When there is resistance it tends increase when the organism was perceived as being more related to humans, with insects being the least related things measured and thus seeing the least resistance. One-celled organisms should be perceived as even less related, so *Tetrahymena* should be even less likely to encounter resistance, making them an excellent model for this content.

Methodology

Game Design

Basic gameplay. The player guides a *Tetrahymena* cell through an environment based on the objects, substances, and organisms found in its natural habitat. Using simple one-button mouse controls, they must direct it to eat smaller bacteria and avoid being eaten by larger predators. Their goal is to eat enough food to reproduce without dying. The interface (Fig. 1) includes a prominent 'food-meter' to indicate progress, as well as several other elements that provide information on the current traits of their cell, and the size and health of the rest of the Tetrahymena population in the environment.

To provide an intuitive, readily identifiable player avatar, and to maximize the number of modules the game's content could be connected to, the organismal level of analysis, or control of a single cell, was used. It provided a middle ground between levels of analysis focusing on either the organelles of the cell's internal anatomy or populations of cells, which allows those levels of analysis to still be relevant and discussed in the module. For example, the avatar uses very noticeable cilia to move, and competes with other *Tetrahyemena* for limited food. A clear avatar the player can identify with also helps increase investment and make that avatar's actions more personally meaningful; in this case it makes the cell's interactions with its environment more memorable and engaging. This allows information about *Tetrayhmena*'s predators, prey, feeding behavior, and responses to substances (such as nictotine residue), to be both conveyed experientially and in a manner immediately relevant to the pursuit of the player's goals.

Reproduction. The "Reproduce" button appears when the food-meter is full, and allows players to access the reproduction interface (Fig. 2). This interface visually presents the history of the generations leading to the current cell, and allows the player to select either sexual or asexual reproduction (as *Tetrahymena* are capable of both). The screen also shows the cell history of potential mates for sexual reproduction, as well as their current traits, which would affect the traits of their offspring. Players can affect the traits of the next generation, either by selecting a mate, or slightly mutating if reproducing asexually. They are then given a choice of offspring and upon selection revert to basic gameplay in control of that new cell.

This system forms both a progression mechanic and meshes with the basic gameplay to form a way to communicate evolutionary concepts in a meaningful way to the players. One important piece of this system is the graphs that dominate this screen. On these graphs, the four traits of cells are organized in two opposing pairs. For example, the blue icons at the top and bottom of the graphs represent movement speed and maneuverability. If a cell gains speed it also loses maneuverability and vice versa. This pair forms an axis and the other traits form a second axis, defining a 2D space where the statistics of any given cell define a point. So if traits change, as they do through reproduction, a new point can be drawn, and a line can connect them representing the change between generations. For example, if a new generation has higher speed, its dot would be higher in the space. This allows the game to visually represent changes between generations to players and to show the accumulation of small changes. The fours traits (speed, maneuverability, hazard resistance, and metabolism) all have direct impacts on gameplay, which make these changes relevant to the goal of survival.

Using these graphs, the reproduction interface provides information about the traits of the previous generations (which the player experienced when playing them) and reproductive choices, as well as information about possible mates. This allows players to reflect on the impacts of their choices and make informed decisions or revise strategies if it appears they are not the best way to pursue their goals.

Level selection The game includes two non-tutorial levels. These levels are designed to favor different sets of traits (one has many predators, hazards, and food bacteria, favoring high hazard resistance and speed; the other has many obstacles and little food, favoring high metabolic efficiency and maneuverability) rather than a difficulty progression. This is intended to show how fitness is contextual and traits may be an advantage in one environment and detrimental in another.

Additional notes To support and foster interest in learning more about the real world organisms presented in the game, all the organisms have both mouse-over tooltips with names and more in-depth entries that provide information both about the real world and tips that are useful within the game. These entries are accessible with a single right-click on the organism of interest.

One significant concern with this design, as with many other evolutionary games, is that the player's active role in the development of their organism may foster the misconception that an intelligent choice is being made during these processes in the real world. In practice, natural selection is a combination of mate selection (which may involve choice, but may not be 'conscious choice' as it is colloquially used, particularly not in single celled organisms) and probabilistic processes, where advantaged subsets of a population produce more progeny than other subsets, and over many iterations become more prevalent in that population. In simplifying this complex system to a more easily understood game design there was the opportunity to focus more on these probabilistic population level effects, but early in the design process this option was discarded in favor of the current design. There were two main reasons for this. First, the focus of the current design is more on how an individual interacts with its environment, rather than pressures' effects at a population level. This smaller scope provides a better entry point for unfamiliar students and can be built on to discuss population level effects later. Secondly, the goals of this project were and are not just to convey content to students, but also to increase interest in and engagement with science. As discussed under "Basic gameplay" there are a number of factors that make the current design approachable and engaging, and those benefits were deemed to outweigh the potential damage of the misconception fostered by the core mechanics. Ultimately, based on the reception of other similar games and discussions with teachers and students, it was judged that the current design was likely to have a more positive impact on students.

This is not to say that fostering a misconception of intelligent choice was not a major concern, merely that it was decided not to address it by altering the design of the game. As this game was designed for use in classrooms as part of a module, there were other opportunities to address this misconception in the associated instructional materials.

Game Module Instructional Design

Previous research (Squire, 2006) described the problems that can arise from teachers and students with little experience with video games in a classroom context, so it is important to provide adequate support for both parties in order for them to get the most out of such tools and experiences. Thus a lesson plan and student handouts, were developed to accompany the game. The lesson plan explained the game and its learning objectives to teachers and laid out two periods of play and discussion around the game. Student handouts were developed to go with these activities. These materials were developed in partnership with the experienced instructors at ASSET and based on frameworks such as the learning cycle. The general structure of the lesson is to repeatedly cycle between game session and class discussions. This structure allows the students to experience the game, develop intuitions and explicit understanding of it, then compare their experiences and understanding with other students, and to connect game experiences to terms and larger concepts. The 'genespace' graphs from the reproduction screen also form a useful tool for these discussions. The graphs provide a common reference and way for students to describe their approaches and attempts to adapt. They then return to exploring the game again with these new connections and ideas in mind, building a richer understanding with each iteration of the cycle.

The suggested discussion points for teachers also allowed for correcting possible misconceptions the game could foster, such as the previously discussed a misconception of intelligent choice. In the lesson, teachers are advised to point out this discrepancy between how the game works, and the more complicated way things play out in reality during the discussion and, if possible, to even build on it to have students consider other ways the game is and is not like reality. In this way the lesson can both address possible issues with the content that could be communicated by the game design and foster critical thinking skills, by have students reflect on exactly what information is being communicated by the game.

Research Design

The research component of this project is ongoing. Currently, a pilot deployment to three local high schools has been completed and more schools are being recruited participate in a wider deployment in the fall. Here, the findings from that pilot, its implications, and the plans for the wider deployment are discussed

Assessment The impact of the different instructional approaches is assessed by a pre-post test. The pre-test consists of two pages, one page of multiple choice (MC) questions about content knowledge and a second page of open ended short answer (SA) questions that includes one asking them to apply evolutionary reasoning. The post test included these two pages as well as a third page with a more difficult series of open ended questions asking students to apply evolutionary reasoning to a novel situation (a sunless environment). The open ended questions were qualitatively coded by trained coders on a high number of dimensions, such as accuracy, length, depth, novelty, etc. The test items were developed in collaboration with ASSET and the content questions were also designed to be relevant to the Next Generation Science Standards (NGSS).

Participants and conditions The initial pilot gathered data from three local high schools. Two of the schools provided pre-post test only of classes that experienced the video game module (n=21, and n=36 at the two sites), while the third provided data on students in the video game module (n=28) as well as a control group that experienced the class's usual instruction on evolution (n=29).

Results Simple t-test analyses with an R statistical package of the MC total scores, indicated that the video game group improved significantly ($t = -2.70$, $p<.001$) as did the control group's ($t=-1.20$, $p=.021$). However the gains did not significantly differ between the two groups. This provides basic validation that the module is as effective as control in terms of factual knowledge. The SA items have shown no group differences, though analyses of these richer responses is ongoing as well.

Informal surveys, observations of, and conversations with students and teachers have also been very positive, with students enjoying the game and teachers seeing it as a valuable addition to their classrooms.

Future Directions

The pre-post measures are currently being revised based on the results of the pilot and teacher feedback. The SA items specifically are being refined to better assess deep conceptual understanding. Measures of engagement and interest in science are being added, to measure possible other benefits of the module beyond content knowledge. The reactions of the students and teachers indicate the video game module is perceived as more effective than standard instruction by both parties. The refined measures will aim to test if these participants are accurately perceiving some advantage (either in terms of learning or attitudes) or if these comments are the result of some kind of bias, such as an overestimation of the effectiveness of new technologies or more enjoyable activities.

Additionally, a larger sample from across the state is being recruited for the next deployment. This should provide both data on how the module performs with a greater variety of students and teaching environments, as well as greater power to examine those differences.

All the teachers in the current pilot wished to continue using the module in the future and if this trend holds for the upcoming larger deployment, *Cellvival!* could provide a good platform to examine a number of further research questions moving forward. Among these are its effects on long-term retention, the persistence of any effects on attitudes, what effect mechanical differences between versions have on the impact of the game, and, similarly, what effect different approaches to using the game in classrooms have on impacts. These effects may all interact with other factors as well, such as interest in science, SES, age, etc. providing even more potential research questions.

Ultimately the core of this project is an effort to develop a meaningful game design and test its effectiveness; beyond that, it aims to provide insights and best practices to improve the effectiveness of subsequently developed games and games based instruction.

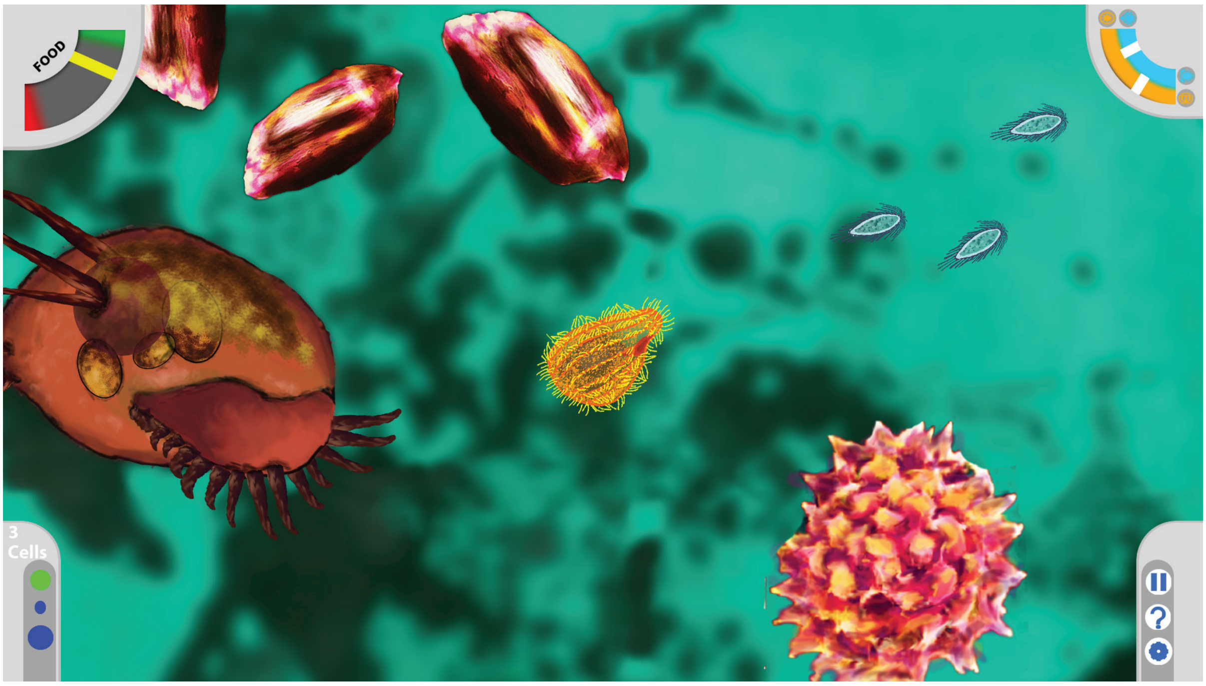

Figure 1: Gameplay as a Tetrahymena cell.

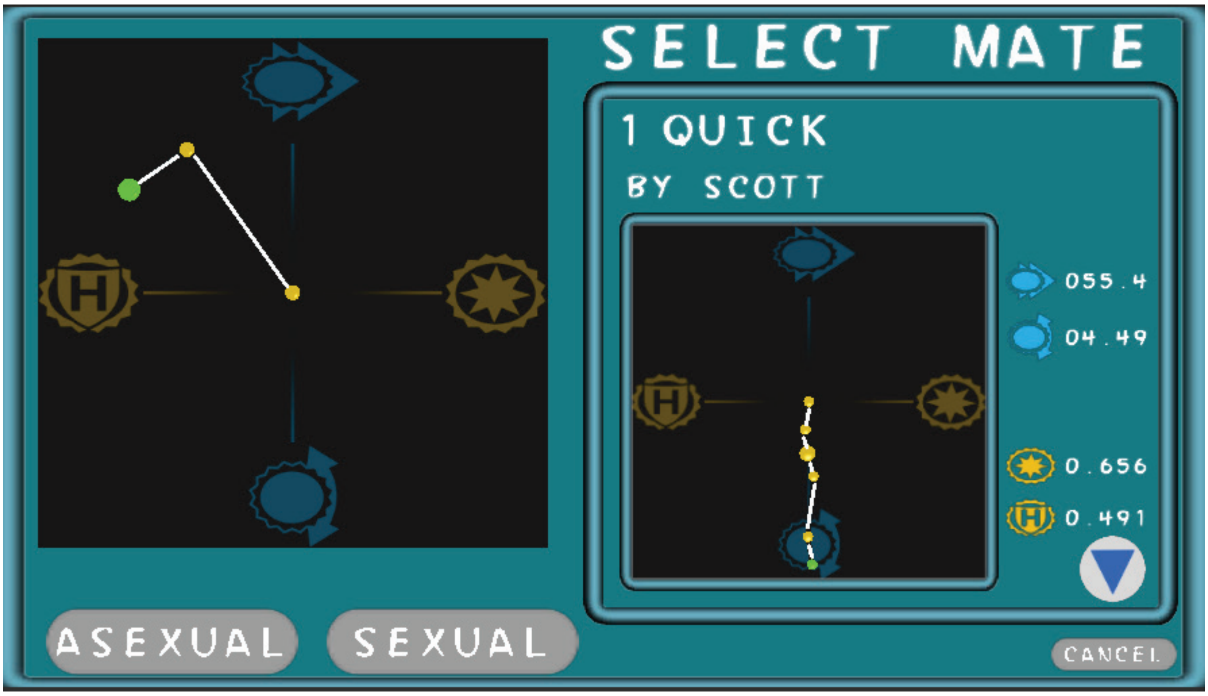

Figure 2: The reproduction interface.

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