Teaching Science Using Digital Literacy and 3D Gaming

Robert Vermilyer

Abstract: This in-progress research project seeks to develop models for educational games that will address, but will not be limited to, the issues of: 1) formulating design strategies that maintain the motivational elements of creativity, exploration, problem solving and being fun to play while at the same time satisfying curriculum objectives; 2) integrating science literacy and computational thinking; 3) integrating gaming into the classroom learning experience focusing on questions of how, where and when to use games; 4) providing methodologies for connecting and applying the STEM skills learned from the gaming experiences to specific engineering problems; and 5) leveraging industry collaboration. The effectiveness of these models will be demonstrated through the creation and application of a 3D 3rd-person exploratory learning game.

Keywords: STEM, learning games, motivation, science literacy, computational thinking

Despite the numerous innovative research efforts to design and implement games to teach STEM related content (Dede & Barab, 2009) (Clark, Nelson, Sengupta, & D’Angelo, 2009) (Niemeyer, Garcia, & Naima, 2009) (Clark, Nelson, D’Angelo, Slack, & Menekse, 2010), the use of gaming in STEM education still remains controversial and not entirely successful. It is our belief that the best way to overcome this controversy and to improve the quality of games is to focus our research on what we see as the four fundamental problems limiting the potential of educational STEM games:

1. Forced content and dissuasive game designs,
2. Lack of reading components,
3. Lack of computational thinking challenges, and
4. Failure to include actual real-world examples and interactions.

We begin with a discussion of our goal and specific objectives, follow with a discussion our strategies for addressing the fundamental problems that we are focusing on, provide an overview of the game scenario and architecture, discuss strategies for incorporating learning games and then conclude with a brief analysis and discussion of our preliminary findings.

Objectives

Introductory high-school science classes are critically important for many different STEM disciplines and careers. Our project’s research lies in developing and testing models of game design with applications across the physical sciences as taught in first year high school science classes.

The goal of this project is to increase the number of high school students engaged in and successful in the study of science through the use of 3D gaming courseware that integrates digital literacy experiences, computational thinking activities and gaming challenges that require the application and formalization of specific knowledge into broader real-world contexts.

Our project is focused on three specific and measurable objectives.

Outcome 1: By Year 2, increase the motivation and engagement of participating high school students to learn science by at least 10%.

Motivation and time engaged in an activity are very closely related. In addition, there is no argument that the mastery of scientific knowledge takes times. Unfortunately, many of today’s high school students are not motivated to devote the necessary time to learn science. There are a variety of reasons for this including 1) the perception that the material is too difficult to understand, 2) the reality that the material is frequently presented in uninterested ways, and 3) the misconception that the material has little relevance to everyday
existence. The proposed gaming experience will help to overcome these, and will therefore directly lead to an increase in the time spent on learning science.

Objective 2: By Year 2, increase the performance of participating high school students on standardized science tests by at least 5%.

Virtually every school in the US would like to improve their students’ science performance as measured by standardized tests. It has been widely documented that the knowledge and skills that associated with higher reading comprehension also drive higher science achievement (Cromley, 2009), (Herman, Perkins, Hansen, Gomez, & Gomez, 2010). In addition, most would agree that fiction more generally can afford engagement, creative thinking and identification with other situations (Bruner, 2002) - we contend that scenario-based educational learning games with an on-going narrative, science fiction vignettes and are playable have the additional potential to increase understanding and retention of STEM topics. This objective will try to be accomplish by embedding the teaching of essential reading and writing strategies for both print and digital environments into the game.

3. Objective 3: By year 2, increase the ability of participating high school student to apply scientific knowledge when engaged in a STEM related problem solving activity by at least 5%.

Computational thinking is a fundamental skill for everyone, not just for computer scientists and engineers (Wing, 2006). However, high school students are seldom exposed to computational thinking. When they are exposed it is typically within the confines of one or perhaps two computer-focused courses. The reason for this is that there is no existing curriculum model for the systematic inclusion of computational thinking within fields outside of computer science and engineering. Adding an interactive exploratory gaming experience that requires the application of computational thinking to high school science courses will help to overcome this problem.

Motivational Design Strategies

The vast majority of psychological research on gaming has focused on its potential ill effects, especially the potential impact of games on human aggression (Anderson & Bushman, 2001) (Gentile & Anderson, 2003). To date there has been little basic research on game motivation, and virtually none related to motivation as it relates to educational gaming. Perhaps the most relevant research is a study applying the self-determination theory (SDT) to an investigating of the motivation for game play (Ryan, Rigby, & Przybylski, 2006). This research also compared the SDT model with Yee’s taxonomy of game play motivations (Yee, 2005). In formulating the educational gaming models and structuring the game, it is our intent to build on several of the findings of this study, including “in-game competency and autonomy are associated with greater enjoyment and preference for future play,” “providing the player with a sense of non-mediated immersion in a game environment is widely valued” and “hours per week was positively associated with achievement and relatedness.”

The under-representation of women and minorities in science, and technology in general, has serious consequences, not only for those whose potential goes unrealized, but also for a society increasingly shaped by technology. High school classes are notorious as a turning point where female and minority students are “turned off” from science and where gaps in achievement, self-efficacy and motivation expand. One of the major conclusions in the celebrated work on the role of women in science, Unlocking the Clubhouse: Women in Computing, was that science curriculum, in particular introductory courses; often focus on solving problems that are not relevant or interesting to female students (Margolis & Fisher, 2001). This work concluded that many introductory science courses tend to be exceedingly tedious and that they often offer very little opportunity for creativity and innovation. Other works have found that in terms of science education, the issues impacting interest and success of women and minorities are very similar (George,
The development of a game that is appealing to female and minority students, as well as to white male students, that emphasizes innovation and creativity will likely result in sustainable advances in teaching and motivating across the entire STEM curriculum. One of the strategies our project shall employ to help insure the game is engaging and appealing is to actually have high school female and minority students aid in both design of the gaming environment and in the conception and development of the expansive cast of game characters. In September 2010, the Arts and College Preparatory Academy (ACPA) in Columbus, Ohio, joined the project. ACPA has a reputation for curriculum innovation, providing students with an interdisciplinary education with a strong emphasis on the disciplines of art, science and ethics, and integrating internships into the traditional high school curriculum. Through their internship program, six talented student artists have already developed a variety concept sketches and drawings. The characters that they have created include a significant number of women and minorities. The following figure provides a small sample of some of their initial art work (Culver) and how it is currently in the process of being converted into 3D models by computer science students (Hunkin) at St. Thomas Aquinas College.

Figure: ACPA Concept Sketches

Incorporation Science Literacy

Major studies have identified that students lack comprehension strategies to understand complex texts and to be able to communicate complex ideas (Ayers & Miller, 2009). The Reading at Risk report (Bradshaw & Nichols, 2004) and other such documents position games and books in diametric opposition to each other, with games presumed to be one of the causes of a decrease in student’s reading despite evidence that problematizes (if not contradicts) such claims (Steinkuehler, 2010). In fact, digital literacy has been identified by the International Reading Association as a “Hot Topic” for 2010 (Cassidy, Valadez, Garrett, & Barrera, 2010). Digital literacy focuses teaching new reading and writing skills and strategies that focus on the need of critical thinking to evaluate the validity and importance of digital text, infer, draw conclusions, make connections to real world problems, and identify overarching concepts that use science learning to make a positive impact on the world.

With respect to learning digital reading and writing strategies for communicating scientific information and ideas, the National Writing Project states that reading and writing skills are “essential to success in school and the workplace” and “cannot be learned on the spot.” (Stoner, 2009). We address this need by embedding reading and writing strategies into the game in order for students to represent their thinking and understanding of scientific knowledge.

Incorporation Computational Thinking

There are two very important aspects related to computational thinking. First, is that computational thinking does not automatically occur in students merely because they are good at playing computer games, using cell telephones, doing instant messaging, or using an iPod®. There is a large difference between happening upon a correct course of action while playing a game and developing a well structured, verifiable and efficient algorithm. Secondly, it is important to realize that in some disciplines, the value of a
computer has become so great that computational thinking is an integral component of the discipline. A report from the National Research Council (NRC, 1999) states computational thinking “can guide and discipline one’s approach to problems in a way that has value well beyond the information technology-programming setting. In essence, programming becomes a laboratory for discussing and developing valuable life skill, as well as one element of the foundation for learning about other subjects.”

Programming can serve as valuable exercise in developing a computational thinker. However, many previous efforts to introduce programming have not been successful, in part because the programming languages have been too difficult to use and the approach is not engaging to students. Recently several methods have been explored overcome these problems by using graphical-based programming environments (Dann, Cooper, & Pausch, 2005) (Resnick, 2010), building and programming robots (Blank, 2006) and using systems based upon physical movement (Good, Romero, Reid, & K., 2008). Therefore, the strategy employed in the gaming models and the actual game will contain computational thinking components via graphical programming challenges.

Game Scenario and Architecture

Far too often educational games have been designed by non-gamers. This had led to games that actually bear little resemblance to a game (Klopfer, Osterweil, & Salen, 2009). In addition, injecting content learning into a learning game where it doesn’t fit will most likely leave the player hating both the game and the content. To address this short coming, the Game Design and Content Development teams will spend considerable effort in crafting and refining a game scenario that will engage players and integrates content in a necessary and natural way. Although our current game scenario has been positively reviewed by serious gamers, occasional gamers, non-gamers, educators and experienced game designers, we will continue to refine it during the coming months.

The following is an abbreviated version of the current game scenario.

Zira, or the main character of the game, explores her virtual world in search of reading pods. Her ultimately goal is to collect reading pods and share them with her friends. Reading pods are found in cave worlds which we calling tintagels. The tintagels can only be entered through discovery portals that are often guarded by examiners. The examiners role is to assure that Zira has the necessary knowledge to be successful in that specific tintagel. Each tintagel focuses on a specific STEM related concept. The following figure illustrates the initial concept of the game’s environment and some of our initial work on a prototype implementation.

In order to support different learning styles (Vark & Mills, 1992), four different types of activities are used for each STEM topic covered in the game. The reading activity involves both factual reading as well as reading original science fiction authored by graduate students in St. Thomas Aquinas College’s Master of Teaching Program. “Science fiction is read [and incorporated into the game] not only for enjoyment, but because it digs into scientific concepts with imagination, creativity, and a thorough appreciation of consequence” (Cernerdza, 2006). The comprehending activity involves facing a variety of different types of question answering challenges. This activity will resemble the effective interaction style used in Study Island® (Mendicino & Razzaq, 2009). The
experimenting activity involves completing one or more virtual experiments associated with the scientific concept for that tintagel. The computational thinking activity will require the writing and testing of an algorithm, abstraction (building a model of a physical entity) or data analysis & representation (Barr, 2011).

We are working with two industry partners, MentorGen Inc. and Lawler Environment Group, LLC (LEG). MentorGen is a development company serving telecommunications providers, power utilities, and the Federal government. Lawler Environment Group is a Woman-Owned Business Enterprise (WBE), certified by the City and State of New York that focuses on construction management and scientific solutions to water related challenges for corporate, private, legal, and municipal clients. The industry partners are providing descriptions of projects that they have recently completed and/or are currently working on, that are serving as experiences that we incorporating into the game. The industry partners will also review the incorporated gaming experiences. In addition, company representatives will visit the participating high schools to discuss their actual projects, offer feedback to students on their solutions and provide general career information.

As an example of this strategy, Tim Lawler of LEG was the engineer in charge of the operations, treatment and infrastructure maintenance and repair of New York City’s upstate water supply. We will create two game challenges based upon his experience. One of the challenges involves the programming of a water monitoring system. This challenge will require the use of information learned in one of the biology tintagels and the computational thinking (programming) tintagel. Another game challenge that will make use of this contribution involves the creation of a water flow management system. This challenge will require the use of information learned in one the physics tintagels. Other game challenges will be developed as this research project continues and additional industry partners join the team.

Some game challenges will involve the construction of Lego® Mindstorms® NXT robots. For example, Sam Wooster of MentorGen, was recently involved in a moving vehicle identification project for the Saudi Arabia government. Students will encounter a gaming challenge based on this real-world project that requires them to make use of knowledge from two of the physic tintagels (light and sound) in order to build a robot that uses light and ultrasound sensors to detect other moving robots. To help support this challenge, the project’s web site will contain a section that supports collaborative problem solving amongst the participating high schools students. Also, information learned from these types of challenges will be needed in order to complete other portions of the game.

**Incorporating Learning Games**

We feel the best teachers try to foster learning environments where students are free to pursue learning in open and exploratory ways, through what is traditionally defined as constructivist learning. Since the spirit of game play sits uncomfortably in many classrooms, the effectiveness and logistics of gaming are frequently problematic. Our project will propose strategies for educational game play. These strategies will build upon the idea that simply using games is not very effective; use is not synonymous with integration (Klopfer, Osterweil, & Salen, 2009). In fact, the use of one strategy often simply means replacement (e.g., a game replacing face-to-face instruction time). It is important to consider how to integrate games into the educational experience and with other activities. Integration requires an understanding of the medium and its alignment with the subject, the instructional strategy, the student’s learning style, and the intended outcomes. Integration of games into the STEM curricula is more likely to be successful than mere game use. In order to achieve integration useful documentation is needed both to enable to teachers to not only get started and also to rethinking and reimagining approaches to integrating educational gaming. Through this project we are developing an *Educational Game Integration Guide.*
Just as the design and implementation of the game is a participatory process in collaboration with the community of educators and industry partners, the creation of the *Educational Game Integration Guide* will be a collaborative effort. We will study the development of the guide using journaling and artifact analysis and the use of the guides using analytics, surveys and interviews. Using this collected data, we will iteratively refine the design of the guide.

**Analysis and Preliminary Findings**

We anticipate the following results from this project to enhance the ability of high school teachers to provide STEM education through employing strategy-based approaches to the cultivation of educational gaming:

- Strategies for encouraging interest in STEM disciplines and careers
- Rigorous documentation of teacher’s approaches, attitudes towards and assessment of educational gaming
- Documentation of new approaches to understanding, introducing and supporting the inclusion of science literacy in educational games
- Documentation of new approaches to understanding, introducing and supporting the inclusion of computational thinking in educational games
- Development of new communities of educators and members of industry

The participating high schools teachers agreed to participate for a variety of reasons but one of the most common elements is echoed in one the teacher’s words is expressed in the following,

> “I believe we should tailor our teaching to what our kids enjoy and make use of what they do, and gaming is part of this.”

In fact, we have found a very enthusiastic response from every high school that we have contacted.

**References**


http://www.all4ed.org/files/PoicyBriefStrivingReadersInformsPolicy.pdf


Culver, E. Zira. Zira. Arts & College Preparatory Academy, Columbus.


