Twenty-First Century Skills and Game-Based Learning

Abstract: Growing number of people around the world engage in playing computer games, yet the educational system has yet to find substantial ways to capitalize on the potential of game-based learning for academic purposes. The purpose of this paper is to draw a connection between two important 21st century skills, i.e., complex communication and expert problem solving, and game-based learning. Specifically, we report on a multidisciplinary research project among computer scientists and educational researchers that is attempting to illustrate the effects of a game-based learning environment on 8th grade student engagement and academic dispositions. Results from this analysis will provide important insights into individual differences among game players that will contribute to future customization of content and game design features. Future data collections will target the effects that using CRYSTAL ISLAND has on student problem solving and interest.

The Connection Between 21st Century Skills and Games

Growing consensus among policy makers and others suggests that if the current generation of students is to be competitive in the 21st century, our education system must be transformed to address the needs of a connected global economy. Central to our system's evolution is defining the knowledge and skills (Partnership for 21st Century Skills, 2005) as well as the performances and dispositions (Dede, 2007) that are necessary for 21st century life and work. Subsequently, K-12 educational experiences and assessments must be designed to align with evolving *21st century ways of knowing, being, and doing.* Obviously, today's students have opportunities to learn in different ways from those of previous generations, with much of the change due to advancements in information technologies. Growing trends among students demonstrate increased passion for and reliance on technologies for entertainment and communication (Pew Internet and American Life Project, 2007). In many cases out of school technology use has lapped in school technology use, even with students from rural and low-income districts (Spires, Lee, Turner, & Johnson, 2007). Schools and educators are searching for proven, low-cost ways to engage students that lead to increased academic achievement.

With growing numbers of people around the world playing computer games, the economic and social implications of this phenomenon are profound. Educators are attempting to find ways to appropriate the best features of game-based learning and bring them into the formal classroom. Not surprisingly, the two 21st century skills of complex communication and expert problem solving (Levy & Murnane, 2004) are dominant features that cut across most game genres. For the most part, traditional schools are not set up to provide learning contexts that promote these two skills. Problem-based learning scenarios have been used for years to try to approximate real life problems and have met with some success in education. But typically problem-based learning modules have not approached the cognitive complexity and fast-paced processing that game contexts afford. Additionally, there is a gap between what students have a growing demand for and what traditional schools can afford. While game-based learning will not be a singular answer to filling the gap, it can provide movement in the right direction.

The modern work environment is about managing complex information streams, which increasingly is a critical part of job performance. Games can provide a context for situated learning in which players are immersed in complex, problem solving tasks that require expertise. Examining the role of expertise in modern culture, John Bransford and his colleagues (e.g., Schwartz, Bransford, & Sears, 2005) distinguish between routine and adaptive expertise. Routine experts are adept at solving routine problems every day; adaptive experts exhibit flexibility, which is highly valued in today's workplace since knowledge and skill requirements change significantly over the course of a career. While routine experts may be efficient and technically skillful, they may not be able to flexibly adapt to solve new problems; adaptive experts are able to adapt to as well as seek out new learning situations (Hatano & Oura, 2003). Adaptive expertise is clearly a key feature of game environments.

Becker & Wade (2004) deconstruct complex communication and expert problem solving further and assert that the following characteristics of gamers map on to the needs of the 21st century workplace. Gamers are able to:

- Rapidly analyze new situations
- Interact with characters they don't really know
- Solve problems quickly and independently
- Think strategically in a chaotic world
- Collaborate effectively in teams

These characteristics are evident in commercial massively multiplayer online games (MMOGs) like *World of War Craft*, or *Everquest 2*. MMOGs share many of the same features of other games except they are played online. Steinkuehler (2004) asserts that these games can be cognitively demanding, requiring exploration of complex, multi-dimensional problem spaces, as well as empirical model building systems. These environments require the negotiation of meaning and values within the online community as well as the coordination of avatars and multiple forms of text. *Civilization III* is an example of a commercial entertainment game that provides extensive experience in problem solving. As players lead a civilization from 4000 BC to the present, they seek out geographical resources, manage complex economies, and hold diplomatic summits with other nations. Squire (2003) conducted a study to see what students learned about social studies from Civilization III, even though the game is designed primarily for entertainment. Students understood the concepts of monotheism and monarchy as well as learned how to synthesize disparate periods of history.

With growing numbers of people around the world engaged in playing computer games, educators are attempting to find ways to appropriate the best features of game-based learning and bring them into the classroom (Gibson, Aldrich & Prensky, 2007). Even the harshest critics agree that most games are engaging, and there is mounting evidence that games offer significant potential for learning. It is widely believed that commercial games such as Civilization, CSI, Age of Empires, Age of Mythology, and SimCity 4 offer some educational value, and research reviews have reported quantitative results on earlier games and simulations (Van Sickle, 1986; Randel, Morris, Wetzel & Whitehill, 1992). Efforts to design *serious games*, which harness commercial game technologies for training, have been the subject of increasing interest in the defense community (Riedl, Lane, Hill & Swartout, 2005), and recent years have seen the emergence of theoretical and epistemological foundations for games (Gee, 2003; Aldrich, 2004; Johnson, 2005; Prensky, 2006). As participants at the National Summit on Educational Games (2006) concluded, the key issue confronting the educational community now is to clearly articulate *why* and *how* games are effective and provide practical guidance for how and under what conditions games can be integrated into the classroom to maximize their learning potential. An essential for educators is whether students can increase their school related content knowledge through a game experience.

The Case of CRYSTAL ISLAND

Becker and Wade's characteristics are also evident in non-commercial games, such as Dede's long standing *River City*, an immersive simulation for middle school students. This MUVE (Multiuser Virtual Environment) is an example of an academic enterprise that was created using designed-based research and promotes both complex communication and expert problem solving. Following the path of *River City,* with the addition of intelligent tutors, CRYSTAL ISLAND, is being developed at North Carolina State University by a team of computer scientists and educational researchers. This NSF funded project (McQuiggan & Lester, 2008; Spires, Turner, Lester, & McQuiggan, 2008) is an example of an academic innovation that targets science education for 8th grade middle students. Taking their cues from Jerome Bruner (1990, p. 35), who observed that the way people organize their experience and knowledge with the social world "is narrative rather than conceptual," the creators are using a narrative centered learning environment to explore concepts related to microbiology (Mott & Lester, 2006).The learning environment (see Figure 1) is set on a recently discovered volcanic island where a research station has been established to study the unique flora and fauna. The user plays the role of the daughter (or son) of a visiting scientist who is attempting to discover the origins of an unidentified illness at the research station. The environment begins by introducing the student to the island and the members of the research team for which her father serves as the lead scientist. As members of the research team fall ill, it is her task to discover the cause of the outbreak. She is free to explore the world to collect physical evidence and interact with other characters. Through the course of her adventure she must gather enough evidence to correctly choose among candidate diagnoses including botulism, cholera, salmonellosis, and tick paralysis as well as identify the source of the disease relying on her knowledge of genetics to solve the mystery.

The task-oriented environment of CRYSTAL ISLAND, its semiautonomous characters, and the user interface are implemented with Valve Software's Source™ engine, the 3D game platform for Half-Life 2. The user can perform a broad range of actions including performing experiments in the laboratory, interacting with other characters, reading "virtual books" to obtain background information on diseases, and collecting data about the food recently eaten by the members of the research team. Throughout the mystery, users can walk around the island and visit the infirmary, the lab, the dining hall, and the living quarters of each member of the team. In the current test bed, there are 20 goals users can achieve, three hundred unique actions the user can carry out, and over fifty unique locations in which the actions can be performed.

We hypothesized that students who participated in the CRYSTAL ISLAND conditions (narrative and non-narrative) would perform better both on science learning and a problem-solving task than students in a control condition. Additionally, we hypothesized that individual student differences could potentially contribute to varying profiles of game-based performance (i.e., navigation traces).

Methods

Participants

Participants included 54 females and 62 males varying in age and race. Approximately 2% of the participants were American Indian or Alaska Native, 5% were Asian, 29% were Black or African American, 58% were Caucasian, 6% were Hispanic or Latino, and 6% were of other races. Participants were all eighth-grade students at ranging in age from 12 to 15 (M = 13.27, SD = 0.51). The students had recently completed the microbiology curriculum mandated by the state standard course of study before receiving the instruments, tests, and interventions of this experiment.

Materials and Procedures

CRYSTAL ISLAND Curricular Development. CRYSTAL ISLAND was designed around five curricular goals. The first goal of the learning environment was to identify that the inhabitants of CRYSTAL ISLAND have fallen ill due to a pathogen. This required users to learn about what a pathogen is and is not. They must also apply this information to the narrative story. The second curricular goal of CRYSTAL ISLAND required users to learn more about viral, bacterial, and fungal pathogens individually. Users must learn about the microbiological structure of these pathogens individually, including the size, shape, and components, in order to complete this goal. The third curricular goal built upon the second, by requiring users to integrate their knowledge about the microbiological structures in order to make comparisons across pathogens' size, shape, and components. The forth curricular goal of CRYSTAL ISLAND required users to create and test hypothesizes about what types of pathogen was causing the CRYSTAL ISLAND illness and its origin. In order to complete this goal, users had to learn about and apply the scientific method, while integrating their knowledge about pathogens. The fifth and final curricular goal was to learn about how one would treat and/or prevent various pathogenic illnesses. The development of the curriculum was aligned with the NC Standard Course of Study for 8^{th} microbiology content.

Pre and Post-test Assessments. Pre-test assessments for each participant were completed one week prior to the intervention. These materials consisted of a researcher generated CRYSTAL ISLAND microbiology content test, demographic survey, problem solving task, and computer attitudes. The CRYSTAL ISLAND content test consisted of 23 questions designed by an interdisciplinary team of researchers and curriculum specialists. Two eighth-grade science teachers critiqued the content test to establish content validity. Immediately following the intervention, students completed the posttest measures comprised of the microbiology content test and the problem-solving test.

Procedures. Students were randomly assigned to one of three experimental conditions: CI narrative (n = 58), CI non-narrative (n = 55), and control (n = 34). The difference between the narrative and non-narrative is that the narrative condition has more storyline details included. Participants in the two CI conditions were first instructed to review CRYSTAL ISLAND instruction materials. These materials consisted of the CRYSTAL ISLAND backstory and task description, a character handout, a map of the island, and a control sheet. Participants were then further directed on the controls via the description sheet.

Participants in the CRYSTAL ISLAND conditions (narrative and non-narrative) had 50 minutes to work on solving the mystery. Solving the mystery consisted of completing a number of goals including learning about pathogens, viruses, bacteria, fungi, and parasites, compiling the symptoms of the sickened researchers, recording features of hypothesized diseases causing the CRYSTAL ISLAND illness, testing a variety of possible sources, and reporting the solution (cause and source) back to the camp nurse to design a treatment plan. Participants in the control condition received all of the curricular information through a self-paced Powerpoint presentation.

Results

Science Content Learning and Problem-Solving Across Experimental Conditions

Analyses of the microbiology content test revealed that overall students performed significantly better on the post-test than the pre-test ($t(149) = 5.51$, $p < 0.01$). Students answered on average 1.6 (SD = 3.3) more questions correctly on the post-test than on the pre-test. Further, the gain between pre- and post-test scores was significant in the non-narrative ($t(55) = 2.97$, $p < 0.01$) and the control conditions ($t(34) = 5.74$, $p < 0.01$); whereas the narrative condition only approached significance ($t(58) = 1.43$, $p = 0.07$).

As anticipated random assignment resulted in no significant differences across conditions in pretest scores, $F(4, 179) = 0.94$, $p = 0.44$. However, learning gains differed by condition $F(2, 149) = 10.38$, $p < 0.01$. As seen in

Figure 1, the largest learning gains occurred in the control condition (*M* = 0.15, *SD* = 0.15), followed by the non-narrative condition (*M* = 0.06, *SD* = 0.14), with the lowest learning gains occurring in the narrative condition (*M* = 0.02, *SD* = 0.11). Bonferroni post-hoc comparisons revealed that the learning gains in the control condition were significantly greater than either of the CI conditions, narrative ($p < .01$) and non-narrative ($p < .01$), which did not differ from each other ($p = .56$).

With respect to the problem solving post-test measure, there were no significant differences across conditions $F(2, 135) = 1.79$, $p <.05$.

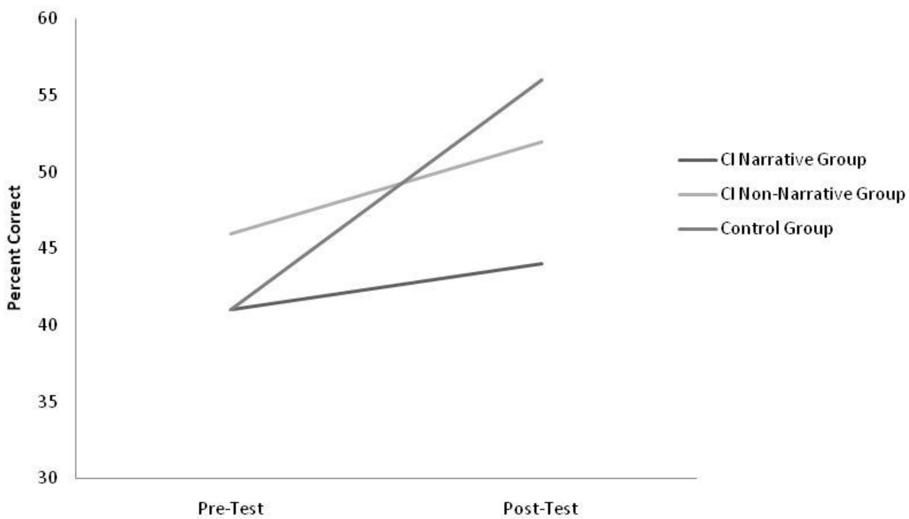

Figure 1. Percentage of correct answers on pre- and post- microbiology content test by condition.

Clusters of Navigation Traces Within the Narrative Condition

Navigation traces describe how each student maneuvered through the game environment. The traces were operationalized by recording the number of cumulative actions and number of plot points completed by each student within the game in 2-minute time intervals. For a two-dimensional representation see Figure 2. Using JUMP Statistical Discovery Software, we used hierarchical clustering to divide students within the narrative cluster into three clusters based on the similarities of their navigation traces. Students who clustered in Cluster 1 ($n = 4$) were efficient in achieving their goals by using fewer actions and solved the mystery (i.e., completed all 5 curricular goals) in the allotted 50 minutes. Student who clustered in Cluster 2 ($n = 17$) were less efficient in achieving their goals and did not complete the mystery. On average students talked to two of the experts and completed only 12 goals and were in the middle of solving the 4th curricular problem. Students clustered in Cluster 3 (n=22) completed on average completed the 5th goal and were working on the 2nd curricular problem. Interestingly, students in Cluster 3 took more notes during the game play than the other two, with a significant difference between Clusters 3 and 2, $t(38) = 5.30$, $p < .027$).

Student Differences in Narrative Clusters

Analyses of Variance (ANOVAs) were conduced to examine differences among the three clusters based on a series of student differences, including performance on the microbiology tests, interest in playing computer games, and performance on problem-solving task. First, results indicated that there were significant differences among clusters in both pre-test and post-test percentage of answers correct on the microbiology content test, $F(2,38) = 4.18$, $p < .05$ and $F(2, 39) = 6.97$, $p < .05$, respectively. Subsequent analyses indicated that students in Cluster 3 (*M* = .38, *SD* = 0.03) had a significantly lower percentage of answers correct on the pre-test compared to students in Cluster 1 (*M* = .55, *SD* = 0.06), but not to students in Cluster (*M* = .44, *SD* = .08) In addition, students in Cluster 3 (*M* = .39, *SD* = 0.03) had a significantly lower percentage of answers correct on the post-test compared to students in Cluster 1 (*M* = .60, *SD* = 0.06) and Cluster 2 (*M* = .50, *SD* = 0.03). In short, students in Cluster 3 both started out and maintained lower scores on the microbiology content test compared to peers in the other two clusters.

Second, analyses indicated that there were significant group differences among clusters based on students' interest in playing computer games, $F(2,38) = 3.62$, $p < .05$, such that students in Cluster 1 (*M* = 5.00, *SD* = 0.00) reported liking to play computer games significantly more than students in Cluster 2 (*M* = 3.41, *SD* = 1.23); but students in Cluster 3 (*M* = 3.80, *SD* = 1.01 did not differ from students in Clusters 1 or 2.

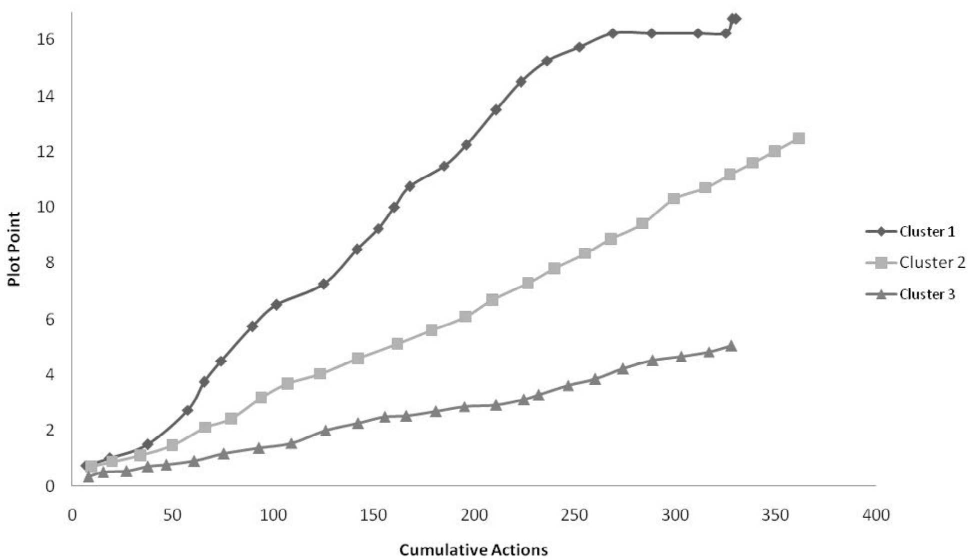

Figure 2. Student trajectories through the game by clusters.

Finally, analyses indicated that there were no differences among clusters for the pre-intervention problem-solving, $F(2,32) = 1.70$, $p > .05$. Interestingly, there were significant differences among clusters based on students' post-intervention problem solving performance $F(2,32) = 3.94$, $p < .05$, such that students in Cluster 2 ($M = 3.73$, $SD = 1.62$) performed significantly better on the post-test problem solving measure than students in Cluster 3 ($M = 2.44$, $SD = 1.15$). Students in Cluster 1 ($M = 3.75$, $SD = .96$) did not differ from peers in the other two clusters.

Discussion

Our hypothesis that students participating in the CRYSTAL ISLAND conditions would perform better on a science content measure as well as a problem-solving task than students in the control condition was not supported. While students in all three conditions increased their science content knowledge, students who were exposed to the content in a direct fashion through a self-paced PowerPoint presentation scored higher than students who participated in the CRYSTAL ISLAND game. Additionally, there were no differences across conditions on the problem-solving task. There are several factors that could contribute to these results. First, in our attempt to control for time on task, we did not provide enough time for all students to complete the game. This, of course, limited potential test performance for students in the CRYSTAL ISLAND conditions since all students were not exposed to the microbiology content. Second, the intelligent version of the software provided customized scaffolding for students as they progressed through the game; it is possible that the amount of scaffolding was not adequate to provide support for all students to successfully navigate the game in the allotted time. Scaffolding was provided for the problem solving process, which we thought could potentially transfer to performance on a post intervention problem-solving task measure. Again it is possible that the amount and/or type of scaffolding were not adequate to provide successful transfer to the post-intervention problem–solving task. Third, while CRYSTAL ISLAND provides substantial motivational benefits with regard to self efficacy, presence and perception of control, (see McQuiggan, Rowe, Lee, and Lester, 2008), it appears that student learning gains are less when compared to a Powerpoint control. It's possible that both the game actions and the narrative storyline could have provided a distraction from the science content to be learned. Finally, even though science learning gains were not detected at the time the post-test was administered, it is possible that learning gains might be detected in a delayed measure. In future studies we will administer a delayed measure of science content to see if students in the narrative condition retain more content as a result of the expository content being embedded within a narrative.

Additionally, we hypothesized that individual student differences could potentially contribute to varying profiles of game-based performance (i.e., navigation traces). Specifically, three profiles of game-based performance emerged (i.e., Clusters 1, 2, 3). Results indicated that students in Cluster 3 performed significantly lower than students in Cluster 1 on the science content pre-test and significantly lower than students in Cluster 1 and 2 on the science content post-test. In effect, students in Cluster 3 were low performers going into the game and stayed lower performers during the game. These students would need additional scaffolding and time to improve their performance.

Students in Cluster 3 performed significantly lower than students in Cluster 2 on the problem-solving task. This is in keeping with the idea that students in Cluster 3 would probably need ample scaffolding during the game in order to transfer any type of problem solving abilities to a post-test task. Students adapted poor or insufficient strategies to make best use of their time. Future research will focus on the use of think aloud protocols to uncover strategy use among participants and how these strategies facilitate or detract from successful game performance.

Previous research has demonstrated the power of intelligent games to engage and motivate students. Based on our results here, it appears that in order to facilitate significant learning gains, students must be given ample time to complete the game as well as customized scaffolding support. Since one unique aspect of a game is that students approach the environment and task idiosyncratically, it is important to capitalize on this phenomenon within the game experience. Our future research will focus on providing more time and appropriate scaffolding to further investigate the possibility that a game experience can increase science content learning when compared to control groups.

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