Measuring Engagement to Stimulate Critical Thinking

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Abstract. This research is a theoretical study of game-augmented instruction for learning and playing mathematics challenges. We wanted to extend our work with a unique Studio-Based Learning (SBL) model for peer-critiques of project designs. SBL had been used successfully in 15 universities as an approach for helping undergraduate computer science students improve their programming skills and code reviews. We piloted the model in a 9^{th}-grade spatial studies class with some success in teaching freshmen how to critique their work and participate in peer reviews across teams. From those experiences we developed a framework for an interactive mobile application of the studio experience. Research with a group of student athletes revealed that before mobile development, we needed to consider the constraints of learner characteristics on the mobile environment. This study sets out the design for a pilot test of our finding that learning style may drive game features for instruction.

Keywords: Mobile Learning, Mathematics, Physiological Measurement, Engagement, Physical Cognition, Game Theory.

1 Background

Research has made great strides in understanding the potential of virtual games to engage learners and advance their learning as effectively or beyond the traditional lecture (Magana, 2009). Understanding the potential that game-based features can bring to instruction is insufficient without first understanding the potential that learners bring to the game. A classic issue for any instructional systems design solution is how to match the pedagogical approach to the learners and the learning context (Dick, Carey and Carey, 2007). We considered the problem of trying to generalize instructional game approaches for all learners, and asked the question: Do specific types of learners require different types of game features for the instruction to be effective? While it may seem an obvious yes, research has more often looked at how to apply known gaming approaches to improve instruction without consideration for the complexity in the learning population. Before we could evaluate the students-to-mobile system for effectiveness in facilitating student critiquing, our research showed we needed to ask more questions about the mobile environment and the students engaged with it. We decided to start with a known instructional problem for a known low achieving student population to investigate how a game-based approach might engage

D.D. Schmorrow and C.M. Fidopiastis (Eds.): AC/HCII 2013, LNAI 8027, pp. 410–417, 2013.

these students in mathematics problem solving. We selected 9th-grade student athletes with low achievement in mathematics as our study population. We then considered which game features might help the learner gain deeper content understanding, and decided on a study of differences in student engagement in a mobile mathematics game, controlled for student learning characteristics.

Our original research was funded on work from a CPATH (Computing Pathways) grant awarded by the National Science Foundation (NSF) to a university collaborative of principal investigators from Auburn University, Washington State University and the University of Hawaii at Manoa. A first CPATH grant (CPATH I) was funded from 2007-2010, and involved the development and testing of a unique Studio-Based Learning model for teaching undergraduates in computer science. A second CPATH grant (CPATH II), from 2010-2012, focused on expanding dissemination of the SBL model to new student audiences. Both grants reported increased engagement in programming tasks and slight, steady improvements in achievement (CPATH II Annual Report, 2011). The foundation of the model was the *Design Crit* (*Crit*), where students participated in peer critiques following a protocol for conducting code reviews. The *Crit* idea was generated from the master-apprentice relationships in the architectural studios of the 19th-Century. The Studio allowed for ongoing critique of students' work by masters and peers at any time in the design process. The SBL classroom is designed as a production studio where students can work, meet in teams, and seek instructor feedback. The NSF offered a Research Experiences for Teachers (RET) supplemental grant to fund expansion of existing CPATH work to K-12. Our research group applied and received a RET grant to pilot the SBL model in the 9th-grade Spatial Studies class at New Technology High School in Napa, California for the academic year 2010-2011.

The two teachers who had been teaching the geometry and digital media arts classes had just been assigned to integrate their classes into a new block class, called Spatial Studies. The grant provided opportunity to write the curriculum and it was developed entirely around a customized SBL model fit to New Tech High's project-based curricula (Donohue, 2011). Replicating the core SBL model from computer science, the Spatial Studies class focused on teaching students to think critically and conduct peer reviews on their geometry and digital designs. We found that students preferred the SBL model over the project-based model at New Tech because it provided them more structure – they "knew what to do next" – and, it gave them more resources from peers in the design reviews. Students reported that they enjoyed learning geometry on the computer as well as on paper and felt that they learned many more digital skills Photoshop, Excel, Illustrator, and GeoSketchpad. Interviews with students at the beginning and end of the class showed that they formulated their learning more precisely and used mathematics terminology more accurately by the end of course. While that would be a natural outgrowth from one year of learning, students attributed their improved understanding to their team critiques and peer-experts, a phenomenon also reported by the teachers.

Our current work in Instructional Technologies at San Francisco State University has focused on the effectiveness of mobile learning and the idea of bringing SBL to a mobile device provided a spark for a small group of faculty and students who accepted the challenge to study a match of learner characteristics to mobile learning games. Our research question asked: Could we engage students in learning geometry by using a mobile game-based approach? If the answer was *Yes*, then we knew we could design a mobile application to facilitate students' critical thinking in geometry.

2 Theoretical Foundations of the Study

This research study focused on the problem of how to engage and help low achieving students learn geometry. We know from the research that computer games and simulations (Regan, et al., 2005; Fairclough, 2009; Magana, Brophy, and Bodner, 2010) can improve student understanding and build self-confidence in learning domain concepts. This was encouraging for a mobile game solution to teach geometry, especially for middle and high school students. We turned our focus to the match of learner to game.

Our study investigated the proposed game's ability to engage low performing students in mathematics. The population consists of sixth and seventh grade students in school sports. We postulated that this group of potentially low achievers in mathematics would be more likely to be engaged in geometry if they could participate in it physically. Our theoretical parameters involved research at the nexus of four fields of inquiry with potential impact on the study's outcomes:

1. The historical use of computing to teach mathematics
2. The success of virtual manipulatives to assist mathematics cognition
3. The principles of Mayer's Multimedia Learning theory
4. The implications of Gardner's Multiple Intelligences

The result was a game pilot that appeals to student athletes' heightened bodily-kinesthetic and visual-spatial intelligences. We developed two mobile applications of a basketball competition for testing: one for a mobile phone and one for Microsoft Kinect 360. The game incorporates findings from virtual manipulatives and multimedia learning theory to shape the environment for greatest effect.

2.1 Historical Use of Computers

James Kaput and Jeremy Roschelle (1998) proposed in their chapter review, *The mathematics of change and variation from a new perspective: New content, new context,* that a Dual Challenge existed with the growth of technology that required teaching "more math to more people" (section *Dual Challenges: Much more mathematics for many more people*, par. 1). They pointed out that, by the turn of the century, teaching mathematics had become increasingly abstract and complex in the face of increasing student diversity and social cost. While pointing out the advantages that new technologies offered, they concluded their review with the question "Can these new possibilities transform our notion of a core mathematics curriculum for all learners?" Their emphasis on "all learners" alluded early to the inability of mass solutions to meet individual needs. More recent work in artificial intelligence that allows for individualized instruction with solutions such as the Cognitive Tutor (Koedinger, 1998) or adaptive testing have run into the same constraints of increased cost, learner diversity, and complexity of content. Our challenge to match the learner to the system would not be a trivial question.

2.2 Virtual Manipulatives

Physical manipulatives have been successful teaching tools in mathematics since their introduction into schools in 1989. Various manipulatives such as base 10 blocks, colored chips, interlocking cubes, and geo-boards proved their worth in helping students conceptualize abstract concepts. Manipulatives allow students to make abstractions meaningful. They facilitate learning by making relationships between ideas explicit using visual, tactile and kinesthetic experiences (Hunt, Nipper and Nash, 2011).

Virtual manipulatives (VM) have shown new potential to engage learners by offering unique characteristics that go beyond the capabilities of physical manipulatives (Moyer-Packenham, Salking and Bolyard, 2008). While virtual affordances can enhance the user's experience and understanding of a mathematics concept, they can also detract or disrupt attention and perception. VM can have drawbacks if not designed well. The visuals can be distracting or disorienting in use, but the authors note that VM was most effectively used in tests with third-grade students when applied in the middle or core part of a lesson: "It was during these activities (investigation and skill solidification) that teachers reported the engagement of the students with the virtual manipulatives" (p.214).

In looking at multimedia principles applied to virtual manipulatives, Packenham et al. (2008) point out that "Dual Coding Theory (Clark & Pavio, 1991) and Multimedia Principles (Mayer & Anderson, 1992) support the notion that when learners are presented with visual and verbal codes, the effects of multimedia instruction and students' recall of information are increased" (p.214). The findings of their study showed that virtual manipulatives "were central to the mathematics learning and content development and were often used in combination with physical manipulatives" (p.215). Our game would need to build on the success of VM in developing content learning.

2.3 Multimedia Learning Theory

Richard Mayer's (2001) Multimedia Learning Theory states that instructional messages should be developed in light of how the human mind works. Mayer's research shows how words and pictures are qualitatively different yet complement each other and that human understanding occurs when learners are able to integrate visual and verbal representations. By building connections between words and pictures, learners are able to create a deeper understanding than from words or pictures alone.

Mayer (2001) bases his cognitive theory of multimedia learning on three main assumptions: 1) Dual Channel - states that humans possess separate channels for visual and auditory information; 2) Limited Capacity - states that humans are limited in the amount of information they can process at one time; and 3) Active Processing - states that humans have meaningful and transferable learning experiences when they engage in active learning as defined by “attending to relevant incoming information, organizing selected information into coherent mental representations, and integrating mental representations with other knowledge.” Our game interface would need to make use of multimedia design principles.

2.4 Multiple Intelligences

Howard Gardner introduced the theory of Multiple Intelligences with his book *Frames of Mind* in 1983. Multiple intelligences theory challenges our traditional notion of intelligence. He argues that multiple intelligences deny the application of a universal or mass approach to measure intelligence, such as the IQ (Intelligence Quotient) test. This suggests that current approaches to instructional development using game theory and gamification approaches might miss the critical determining factor of individual differences. One advantage of games is their potential for customization or personalization by the user. However, the ability of the user (learner) to select or dress the player in the game to suit his or her preferences does not address the need alluded to here for learners to choose a type of game that fits his or her learning approach.

Our selected learners for intervention are student athletes involved in school sports. Gardner (1983) explains intelligence as raw biological potential to process information and problem solve. The two intelligences important to this study are the bodily-kinesthetic and visual-spatial intelligences.

Bodily-kinesthetic intelligence has been defined as “the ability to problem solve or fashion products using one’s whole body, or parts of the body” (Gardner, 1993). Bodily-kinesthetic learners process information through the sensations they feel in their bodies and tend to learn through movement and touch. Individuals with this intelligence prefer to communicate information by demonstration and modeling. These learners include athletes, dancers, actors and surgeons.

The visual-spatial intelligence has been defined by Gardner (1993) as, “the ability to form a mental model of a spatial world and to be able to maneuver and operate using that model.” Individuals with high visual-spatial intelligence tend to think in pictures and are able to learn readily from visual presentations. Our most surprising finding alerted us that our game would likely be more effective if we could meet our student athletes’ learning preferences.

2.5 Ways That Games Engage

We chose to build a mobile application based on the principles and lessons of multimedia learning, virtual manipulatives, and multiple intelligences noted above. We know from the research that gamification of instruction offers numerous ways to engage learners in content: rewards for achievement, instant feedback, enhancement of attention, a state of uncertainty that triggers Dopamine for heightened enjoyment, and engagement by playing with other people (Chatfield, 2012; Gee, 2005; Camerer, 2003). Given these challenges for design and development of the platform, we designed a study as outlined in the methods section that follows.

3 Methods

We chose to design an Augmented Basketball Challenge. Our interests for the pilot were to explore three areas of investigation: 1) the role of visual-spatial and bodily-kinesthetic intelligences on learning with the game, 2) the attraction of a mobile (or virtual) game to engage low-performing students in learning, and 3) the ability of physically augmented cognition to impact students' conceptual thinking in geometry.

Our first prototype, the Augmented Basketball Challenge, places young players in friendly competition to demonstrate their understanding of triangles, angles, parallel and perpendicular lines. More than a classroom manipulative; more than a simulation; the Augmented Basketball Challenge uses a virtual 3D competition to stimulate student understanding of mathematics by physically manipulating a visual basketball in live play. The pilot test will explore the physical-cognitive link during game play. We know from Purdue's worldwide research on Nanohub.org (Magana, Brophy, and Bodner, 2010) that simulations can improve student understanding and build self-confidence in learning domain concepts. We know, as Howard Gardner (1993) suggests, that students' spatial and bodily-kinesthetic intelligences act as cognitive aids to learning when body, mind, and game converge. To gain deeper insight into the potential effects of these principles on mathematics learning, we are conducting a mixed methods study of the game's implementation with middle school students.

We have chosen the methods employed by Regan, Mandry, Kori, Inkpen and Calvert (2005) in their study using questionnaires, interviews, video coding of observations, and Galvanic Skin Response (GSR) to measure the user experience with entertainment technologies. While their study used a hybrid game system to analyze the differences between computer systems, we will collect the same type of data from four student groups in a 2x2 design: student athletes with low mathematics scores on the 8^{th} grade high stakes testing, student athletes with average to above average mathematics scores, student non-athletes (scoring low on bodily-kinesthetic and visual-spatial intelligences testing) with low mathematics scores, and student non-athletes with average to above average mathematics scores. Each group will participate (within-group) in the Augmented Basketball Challenge on the mobile application and then one round on the Kinect 360. Videos during game play will capture gestures, facial expression, and audio. A likert-based questionnaire before participation will capture student perceptions and attitudes towards mathematics and geometry in particular, experience with video or online games, and any experience with educational games. Post group interviews will be taped and conducted immediately after participation. The interviews will collect information on students' perceptions of the game and their experience, attitudes and perceptions on the geometry challenges, their preferences for learning with mobile devices and their observations of the game experience.

3.1 The Game Design

The game covers geometry basics from the 9^{th}-grade mathematics standards on identifying triangles, angles, parallel and perpendicular lines. The game gives students opportunity to practice the standards and assess their learning. They also have the chance to compete with other students and engage in the social aspects of the game. The mobile application model presents live basketball footage that demonstrates a standard. The video is enhanced with graphics to add demonstration of the concept. For example, to demonstrate a right angle, a player may pass the ball from one player to another player and then a third player forming a right triangle. The result is shown with arrows on screen. Student mathematics' assessment will occur through competition, either with the computer or against each other. Game competition will be timed and continuous. The time is shown as a shot clock on a basketball court. The game presents students with a series of mathematics terms, given one at a time, in random order. The player must perform the concept of the term presented and shoot. Every correct calculation scores a point. The highest point wins. The game will be personalized for players with their picture added to a player's scorecard.

iPad Simulation. The student uses fingers to swipe the motion of the ball in a trajectory. After completing an angle, the student shoots the ball by swiping it towards the basket. If the basket is made, the student's calculation was correct. If the basket is missed, the calculation was incorrect. Lines and Arrows demonstrate where the ball has been passed (See Fig. 1). Onscreen colors signal correctness of actions and rewards are used to encourage play and challenge the learner.

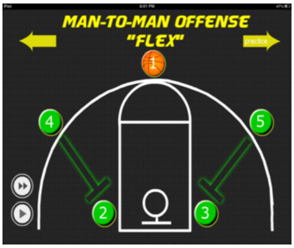

Fig. 1. Screen shot of test iPad application for teaching basketball plays, showing ball trajectories (green) and touch controls at lower left. Developed by Tawnya Gray.

XBOX 360 Kinect Simulation. The game operates as in the iPad simulation; however, instead of a swipe of the finger, the student simulates a passing motion of the ball in the trajectory desired, for the player on-screen to catch it. The student is always the player with the ball. When the student *feels* the correct answer they will shoot the ball (the same way as if they were on a real basketball court). Onscreen, the game shows the player shooting the ball. If the student's calculation is correct, the ball makes the basket; if incorrect, the student misses the basket.

4 Implications of the Study

In 2011 there were 34,024 student-athletes participating in the sport of basketball for NCAA (National Collegiate Athletic Association) affiliated institutions of higher learning. Most of these students enter four-year institutions as freshmen and are required to learn a significant amount of basketball tactical plays in order to compete. College basketball tends to have a high attrition rate of freshmen student-athletes who must successfully make the transition from high school to college. We looked at this population of students who are challenged on at least three fronts. They must successfully transition from high school to college academic standards, athletic standards, and to a higher-level basketball game. These students were often the low achievers in mathematics and other academic disciplines. If we can teach these athletes mathematics using a physical basketball game framework in high school, we might be able to help collegiate athletes before they reach their freshman year learning trauma.

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