



Innovation in research and engineering education:
key factors for global competitiveness
*Innovación en investigación y educación en ingeniería:
factores claves para la competitividad global*

DEVELOPMENT OF NATURAL-GESTURE, GAME-BASED ENVIRONMENTS FOR MATHEMATICS AND STEM EDUCATION

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Abstract

With the growing commercial availability of kinesthetically-interactive computational environments, the use of gesture-based technology in education for various subjects and grade levels has been gaining momentum worldwide. The premise of natural gesture-based learning is that the use of natural gestures enhances the absorption, retention, and engagement of students in the learning process. However, the abstract nature of mathematics has historically posed a challenge in effectively leveraging visual and kinesthetic components that complement traditional learning mediums. This research examines the impact of kinesthetically-enhanced, game-based environments in undergraduate mathematics education at a research university in the United States. More specifically, experiments are being designed to analyze the utility of gesture-based games when the content, gesturing, and delivery are all designed synergistically for effective transfer of calculus and statistics course concepts. The design of the natural gesture framework in development is extensible to other science, technology, engineering, and mathematics (STEM) subjects, and supports built-in customization, like the generation of gestures for the illustration and demonstration of complex mathematical concepts. The framework utilizes Omek Interactive's Gesture Authoring Tool (GAT), the Beckon Motion Toolkit, and the Soft Kinetic IISU middleware for integration into the Unity3D game engine. These tools permit the creation of simple, content-specific, customized gestures. Conventional classroom learning materials, i.e. lecture and supplemental notes and texts, comprise the content adapted for the lesson modules embedded throughout the interactive game environment. So far, this work has focused on the game development in order to ensure consistency and accuracy of the game's content when compared to the traditional lecture materials for the math courses being studied. The evolution of the natural gesture-based game prototype as an innovative educational system constitutes the key product of this research effort to-date. Development of the experimental design for the impact analysis of the novel, innovative educational platform is currently underway.

Keywords: natural gesture; game-based learning; math education

Resumen

Con la creciente disponibilidad comercial de los entornos computacionales cinestésica interactivos, el uso de la tecnología basada en gestos en la educación para diversas materias y grados escolares ha ido ganando impulso en todo el mundo. La premisa es que el uso de gestos naturales, mejora la absorción, retención y participación de los estudiantes en el proceso de aprendizaje. Sin embargo, la naturaleza abstracta de las matemáticas ha planteado históricamente un desafío en el aprovechamiento eficaz de componentes visuales y cinestésicas que complementan medios tradicionales de aprendizaje. Esta investigación examina el uso de componentes cinestésicas en entornos basados en el juego en la educación matemática de pregrado en una universidad de investigación en los Estados Unidos. Más específicamente, estamos diseñando experimentos para analizar la utilidad de los juegos basados en gestos cuando el contenido, haciendo un gesto, y la entrega están diseñados de forma sinérgica para mejorar la transferencia de cálculo y estadísticas conceptos del curso. El diseño del sistema de desarrollo es extensible a otras ciencias, tecnología, ingeniería y matemáticas temas, y es compatible con la personalización, tales como la creación de gestos para la ilustración y demostración de conceptos matemáticos complejos. El marco utiliza la herramienta de Omek Interactivo Gesto Authoring (GAT), el kit de herramientas de Motion Beckon y el middleware IISU Soft Kinetic para la integración en el motor del juego Unity3D. Estas herramientas hacen que sea posible para crear gestos personalizados que son simples y de contenido específico. Apuntes de clase tradicionales y los textos fueron utilizados para desarrollar los módulos de lecciones para el entorno de juego interactivo. Hasta el momento, este trabajo se ha centrado en el desarrollo del juego con el fin de garantizar la coherencia y precisión de los contenidos de juegos en comparación con los materiales tradicionales que se enseñan en los cursos. La evolución del prototipo de juego como un sistema educativo innovador uso de gestos naturales es el producto clave de este esfuerzo de investigación hasta la fecha.

Palabras clave: *gesto natural; aprendizaje basado en juegos; la educación matemática*

1. Introduction

Of all students starting a STEM program as an undergraduate in the United States, approximately 15% complete his or her degree program, and 30% to 35% of those starting in STEM field switch to alternate degree programs outside of STEM disciplines (Augustine, *et. al.*, 2007). Though the factors contributing to STEM degree completion rates vary, they clearly indicate one way of increasing the number of STEM professionals in the near-term is to target the retention of students in undergraduate STEM programs (Business Higher Education Forum, 2010). A critical aspect of achievement and completion of STEM-related curricula at any level (elementary, secondary, or post-secondary) is the student's degree of engagement with course content (Johnson-Glenberg, *et. al.*, 2011). This research aims to improve the ability of undergraduate STEM students to learn and retain presented information through the design and realization of a participatory educational gaming application in which they are able to actively interface and experience given subject matter via natural gesture controls.

Increasing affordability of natural gesture recognition technologies, including Microsoft Kinect®, in conjunction with development of robust SDKs allow this approach to be a cost-effective means for developing more engaging course content experiences. Enabled by the advancements in depth sensor cameras over the last decade, natural gesture interfaces offer the promise of a more intuitive form of object-based control during the exploration of virtual environments (Fernando, *et. al.*, 2000), in comparison to other control modes, such as remotes or keyboards. In addition, using natural gestures to navigate and

control visual software environments presents a unique way of exploring multi-dimensional information for real-world problem scenarios, affording greater ease in exploring complex visual content typically encountered in mathematics applications. Furthermore, the complex narrative and interaction mechanisms, like game level unlocking features, can help keep students motivated to solve increasingly complex problems. Creating games with features customizable to the user's personal interests further provides a way to explore and potentially reduce differences in retention rates among varying student subpopulations entering STEM programs.

By creating an education gaming application that offers an immersive, fully interactive and navigable environment, the individual student's curiosity and eagerness to play the game, can motivate their continued engagement with course material, rather than their ability to pay attention for extended periods of time. Furthermore, the non-linear style of learning brought about by an interactive environment allows users to skip material they already know, and select topics relevant to their individual needs and interests. The development of a natural gesture framework for math subject matter, with built-in customization, like the ability to build gestures for the illustration and reinforcement of standard mathematical concepts, is well underway for this research effort. The rest of the paper outlines how this ongoing research is evolving to enhance the effectiveness of undergraduate mathematics education through the use of natural-gesture enhanced, virtual learning environments.

The primary research question being investigating is whether the use of gesture enhanced, visual learning environments in mathematics education results in improved learning outcomes. The success of innovative components for learning, including gestural and game content for serious contexts (Knutz, *et. al.*, 2012) will be determined through analysis of student test results under varying conditions. Learning outcomes will be analyzed through a three-stage analysis of pre-test, post-test, and retention test. Results will be evaluated down to the concept level to determine the effectiveness of developed interaction methods and relevant content. We will also address cognitive load issues through multimodal content delivery and whether certain modes of content alone or in combination are more effective than others in educational content delivery (Mayer, *et. al.*, 2008).

2. Prototype Development

2.1 Framework of the Natural Gesture, Educational Game

So far, this research has focused on the development of an educational, gesture-based game integrating concept-level content from undergraduate level calculus or probability and statistics courses, currently entitled 'Eridanus'. The work from previous research studies concerning the effectiveness of gesture usage in the learning process (Goldin-Meadow, *et. al.*, 2009), (Goldin-Meadow, 2010), as well as the effectiveness of gaming as an educational delivery method (Amory, 2010) continues to inform ongoing evolution of the system framework. The framework utilizes Omek Interactive's Gesture Authoring Tool (GAT), the Beckon Motion Toolkit, and the Soft Kinetic IISU middleware for integration into the Unity3D game engine. These tools permit the creation of simple, content-specific, customized gestures.

The game prototype allows players a mode of self-guided teaching as they navigate levels, a departure from the traditional system used in school textbooks. For example, conventional calculus texts typically present the concept of a derivative first, prove it mathematically, walk through four or five examples of a derivative, and then place all problems for students to solve at the end of the pertinent chapter. Once these text-based problems are exhausted students are out of opportunities to practice and check their work

in one convenient place. In contrast, in the interactive, educational game in development, a player who selects calculus as their topic, is asked questions about derivatives before they ever see a paragraph or a chart describing what a derivative is. If they are familiar with the concept, they can solve the problem and move onto something more challenging. If the concept is unfamiliar to them, they can gesture to ask for help determining what a derivative is. The game's purpose is to educate players while entertaining them; mitigating the stress that can accompany learning difficult topics. The primary form of education in *Eridanus* takes place through the problem solving required to unlock specified containers and doors (Figure 1).



Figure 1 - Encountering a locked cargo container aboard a ship and overriding the locking mechanism by solving a question from a calculus course.

If a player incorrectly responds, they are able to reset the lock to receive a new problem. Assessment algorithms are being integrated to track how players progress. When solving a problem, the player can ask for help, or ask to see the answer. Asking for help will give players a visualization of the problem and/or some supporting textual information. Asking for the answer will give players the answer, but will also automatically reset the lock, generating a new question to be solved until mastery of the subject matter is achieved without seeking the problem's answer.

The lock level (which scales from 1 to 5) indicates the difficulty of a given problem. Lower level containers require players to solve easier problems, and the rewards are moderately satisfying. Higher level containers ask them to solve more difficult questions, but promise greater rewards that make the struggle worth it in the end. Players, i.e. students, enjoy these problems because they receive something of value every time they are correct. The items that are gained by opening a locked container vary from credits, to items, or both. Sometimes the player may gain access to a small piece of the story by solving a problem, motivating them to solve all the problems of a selected mission to ultimately see the full picture.

2.2 Example Gesture Library

The natural gesture controls of *Eridanus* are designed to be a departure from traditional Kinect® controls, which consist of mostly poses and very few actions. Far too many games use mere “swipe” gestures where

analog inputs would suffice, or require that users perform a certain action (for example, jumping) only when prompted by the game. *Eridanus*' controls are designed not only to feel intuitive, but to mimic how an astronaut in a high-tech space suit might freely move about in space. Table 1 presents a sample list of natural gesture controls, and their resulting actions in the game environment. As players unlock new upgrades, they will receive more abilities that can be triggered by additional gesture controls.

| Gesture | Game Action |
|---------------------------------|--|
| Bring left hand to left ear. | Toggle helmet mounted flashlight |
| Bring right hand to right ear. | Open voice communications with operator back on the ship |
| Bring left hand to mid torso. | Display help with the topic the player is currently learning |
| Bring right hand to right shin. | Sheathe/unsheathe knife |

Table 1 - Sample natural gestures and their resulting actions within the game.

3. Experimental Design to Test Impact of the Interactive Educational Game

The hypothesis validation and testing procedure aims to determine the efficacy of Natural User Interface (NUI) educational content delivery methods in comparison to traditional classroom learning methods as measured by immediate test performance, retention of knowledge and engagement in the learning process. To explore the validity of the hypotheses, several control and test groups each analyzed for different aspects of the research question are considered.

3.1 Control and Test Group Selection

The control group will be composed of undergraduate students from the researchers' university enrolled in an intermediate Probability and Statistics course from various departments including Mathematics, Business Intelligence and Analytics, Engineering Management, and Management in order to analyze discipline specific concepts. The test groups will be composed of undergraduate students having difficulty with particular concepts who will be drawn from students enrolled in the Probability and Statistics course. These students will be identified by faculty and/or self-selected through concept performance. Others will be students recruited from the university community who will have not yet taken the Probability and Statistics courses.

3.2 Preliminary Concept Selection for Lesson Content

Selected topics from each course will be integrated into the gesture-enhanced gaming environment and the performance of the test group students will be assessed using identical questions to those presented to the control group by their instructors. Each control subgroup will then be analyzed individually for efficacy of NUI educational game content delivery. For example, table 2 shows the mean scores and standard deviations of student scores in an intermediate probability and statistics course at the researchers' university according to topical concepts. Based on this table the first experiments will be related to the concept of 'model utility determination' in statistics since it exhibited lower mean scores among the set of concepts covered.

| Sample Statistics Concepts | Related Assignment Mean Class Score (%) | Standard Deviation (%) |
|--|---|------------------------|
| Random Variables, Sampling Distributions | 83 | 11 |
| Confidence Intervals and Testing Hypothesis on Population Means and Proportions | 81 | 20 |
| Two Population Tests of Means and Proportions | 81 | 15 |
| Test of Population Variance and Two Population Variances | 78 | 25 |
| Simple Linear Regression. Least Squares Fitting. Analysis and Testing Model Utility. Prediction of Future Values | 63 | 31 |
| Multiple Regression. Data, Model Estimation of Regression Parameters. Multiple R^2 , Residuals. | 68 | 34 |

Table 2 - Mean class performance for sample of statistics course concepts for a single class occurring within the last two academic years.

3.3 Data Collection and Analysis

Understanding of mathematical concepts for the control group and testing group will be evaluated through collected performance data as well as pre-test/post-test analysis. Each group will be given a pre-test on the material to be covered, then a post-test after the learning module has been addressed in class as well as through the gestural learning interface. A third test will be given to analyze retention, to determine whether NUI learning methods are a more effective tool for retaining information. Collectively these tests will determine each student's background knowledge on the material being presented, the effectiveness of the learning method as measured through test results, and the ability to retain the information learned given the passage of a determined period.

For the initial testing, students taking part in the NUI testing group will be requested to interface with the educational content through a series of pre-programmed gestures that they will be taught as a preface to the educational content delivery process. Performance through usage of these gestures will be analyzed to determine their respective effectiveness in complementing engagement with course materials.

4. Summary and Next Steps

This work presents the ongoing development of an educational game that utilizes natural gesture capabilities to better engage students with STEM, more specifically statistics, course content. Continuing development of the game environment will potentially enable a new mode for knowledge delivery, particularly for students struggling with STEM materials. The first implementation of the prototype contains lesson content from a single intermediate course in probability and statistics. The plan to assess educational merit is to analyze the lock-picking approach to problem solving (mentioned earlier in reference to the game's framework) embedded in the game in comparison to conventional lecture-style course deliveries. Combining this approach with the presence of interactive information visualizations within the game environment provides an interactive educational environment that is prospectively superior to those found in existing educational

applications. The next steps of this research project involve the final testing of the game prototype, and execution of the experimental design for the determination of the innovative educational game's impact on student learning outcomes.

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