Overview of Game and Content Design for a Mobile Game that will Prepare Students in Calculus and Physics Prerequisites to the Engineering Curriculum

Ms. Katherine Smith, Old Dominion University

Katherine Smith received B.S. degrees in applied mathematics and mechanical engineering from Old Dominion University and an M.S. in Applied and Computational Mathematics from Old Dominion University. Ms. Smith is currently a lecturer in the Department of Mathematics and Statistics at Old Dominion University and is pursuing a PhD in Modeling and Simulation. Her research interests include serious games for STEM education, scientific visualization, and augmented and virtual reality. Prior to teaching at ODU, she worked as an Aerospace Engineer at NASA Langley Research Center.

Mr. John Shull, Old Dominion University

John Shull is currently enrolled in the Batten College of Engineering and Technology (BCET) at Old Dominion University pursuing a PhD within the Modeling, Simulation, and Visualization Engineering Department. His research is in the use of virtual environments, augmented (AR) and virtual reality (VR) engineering, the use of serious games for advancements in education, data visualization techniques with AR/VR technologies, and Agent Based Modeling applications involving complex systems.

Mr. Patrick Sean Heaney, Old Dominion University

Patrick Heaney is pursuing an M.S. in Mechanical Engineering at Old Dominion University (ODU). He received an M.S. in Education from the University of Pennsylvania (2014) and a B.A. in Economics and Mathematics from Yale University (2009). After graduating from Yale, Patrick served in the Marine Corps Reserve and taught 6th Grade Mathematics at LEAP Academy University Charter School in Camden, New Jersey.

Prof. Yuzhong Shen, Old Dominion University

Yuzhong Shen received his B.S. degree in Electrical Engineering from Fudan University, Shanghai, China, M.S. degree in Computer Engineering from Mississippi State University, Starkville, Mississippi, and Ph.D. degree in Electrical Engineering from the University of Delaware, Newark, Delaware. His research interests include computer graphics, visualization, serious games, signal and image processing, and modeling and simulation. Dr. Shen is currently an Associate Professor of the Department of Modeling, Simulation, and Visualization Engineering and the Department of Electrical and Computer Engineering of Old Dominion University. He is also affiliated with Virginia Modeling, Analysis, and Simulation Center (VMASC). Dr. Shen is a Senior Member of IEEE.

Dr. Anthony W. Dean, Old Dominion University

Dr. Anthony W. Dean has had several roles in academia. His previous appointments include Associate Professor of Engineering Technology and as Associate Director of the Institute for Ship Repair, Maintenance, and Operations at Old Dominion University (ODU). He is currently on assignment with the Office of the Dean for Sponsored Programs and the Engineering Fundamentals Department, Batten College of Engineering and Technology (BCET) at ODU. His research has focused mostly on control systems (integration and testing) and the reliability and maintainability of complex systems. He has been selected as both a NASA and an ONR Faculty Fellow. He regularly teaches courses in Marine Engineering and in Maintained Systems. Most recently Dr. Dean was on the Headquarters Staff the American Society of Naval Engineers. He received his Ph.D. from the Department of Engineering Management and Systems Engineering, and a B.S. in Nuclear Engineering Technology, from the Batten College of Engineering and Technology at Old Dominion University. Additionally, Dr. Dean received an MBA from the College of William and Mary. Prior to is academic career Dr. Dean was Director of Operations and Business Development for Clark-Smith Associates, P.C., and served as an Electrician in the US Navy aboard the USS South Carolina and the USS Enterprise.

Dr. Jennifer Grimsley Michaeli P.E., Old Dominion University

Dr. Michaeli is an Assistant Professor in the Department of Engineering Technology of Old Dominion University. She received her PhD in Mechanical Engineering from Old Dominion University, her MSc in Ocean Systems Management from Massachusetts Institute of Technology, and her BSc in Naval Architecture and Marine Engineering from Webb Institute. Prior to her arrival to ODU, Dr. Michaeli over 15 years with the Department of Defense and industry as a Naval Architect and Program Manager where she carried out design and engineering, construction and testing for marine vehicles. At ODU, Dr. Michaeli's research and educational interests include topics concerning naval architecture, marine engineering, design, manufacturing and testing of composites and lightweight structures, and engineering multi-criteria decision methodologies. Dr. Michaeli is actively involved in industry-government-academia partnerships to further the advancement of naval and marine engineering.

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Introduction

As part of a research project which assists veterans as they exit the military, complete engineering degrees, and enter the workforce as engineering professionals, a range of serious games for Science, Technology, Engineering, and Mathematics (STEM) education is under development (1). The current focus of this development is CAPTIVATE, a serious game to assist student veterans in mastering the calculus and physics skills that are necessary prerequisites to the main engineering curriculum. Building on the development and lessons learned from MAVEN, a game developed previously to help student veterans master precalculus skills, the design and initial implementation for CAPTIVATE involves careful consideration regarding game and instructional design. Many of the positive aspects from the design of MAVEN have been implemented in CAPTIVATE. First, the overall framework developed for MAVEN has been reused. This modular framework involves both a model and process that combine game, instructional, and software design in a way that supports adaptability throughout the design and development cycle. Additionally by embedding concepts in game play similar to well-known board games such as Battleship, computer games such as Minesweeper, and console or mobile games such as Guitar Hero, students will use their calculus and physics skills to complete tasks in a familiar environment. The game itself consists of a series of sub-games each focusing on a topic that students traditionally struggle to understand. Furthermore, students will be offered access to learning resources and assessed regularly as they progress through the game. CAPTIVATE overcomes some shortcomings from the previous development. While MAVEN was developed for desktop deployment, CAPTIVATE is targeted for deployment on a variety of mobile device including Apple and Android phones and tablets to engage students in interactive games that support their endeavor to build a solid foundation in mathematics and science topics. Furthermore by creating games that are short and easily accessible, students will be able to engage with the material at a time and place convenient for them. The development of CAPTIVATE supports student veterans as they transition from the military to engineering degree programs and helps to accelerate them through their STEM prerequisite courses. While the current work is specifically aimed to help military veterans as they work to earn engineering degrees, all games developed through this project will be made available for download free of charge to the public.

The remainder of this paper is organized as follows: First, an overview of MAVEN and CAPTIVATE are provided. Next, there is a discussion regarding how the framework developed for MAVEN was reimplemented to accelerate the development of CAPTIVATE. Then, there is an overview of some of the games developed for CAPTIVATE. Finally, conclusions and future work are discussed.

Previous Work: Overview of MAVEN

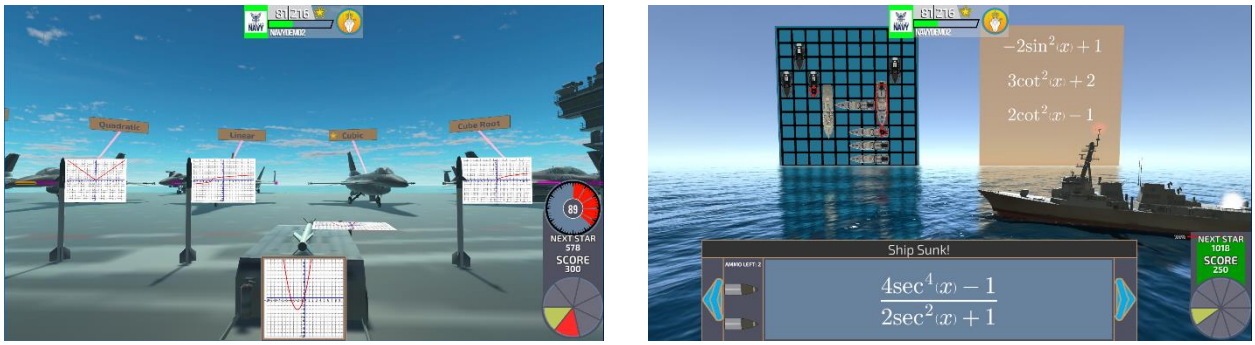

Figure 1: Selected screenshots from MAVEN showing two games. The game on the left requires students to match transformed functions with their parent function type. The game on the right requires students to solve problems involving trigonometric identities.

MAVEN was developed as the first in a series of serious games addressing common deficits in STEM general education knowledge for students pursuing engineering degrees. To refresh prerequisite knowledge and prepare students to succeed in Calculus and beyond, MAVEN focused on precalculus topics. Knowledge from subject matter experts and current tutors was combined to identify three main areas of weakness. These areas were functions and graphing, trigonometric functions, and exponential and logarithmic functions. A series of games were designed that required players to engage with content, play through games that required them to practice their mathematical skills, and be assessed at set intervals. Two example screenshots from MAVEN are included in Figure 1.

Current Work: Overview of CAPTIVATE

CAPTIVATE is the next game in the series and will help engineering students overcome difficulties in their first calculus and physics courses. The decision was made to combine the two content areas since physics is essentially an application of calculus. Especially for engineering students, mathematical concepts can be more readily understandable when presented alongside their physical applications. It is suspected that this will be true particularly within the target audience for CAPTIVATE which includes military service members who have obtained specialized technical training as part of their military service.

CAPTIVATE is designed to improve upon the shortcomings of MAVEN while preserving its successes. One of the key aspects preserved is the Learn, Play, Assess methodology. In both games, content is available to help remediate skills when the player is struggling. The play component involves the player engaging in game play to practice their mathematics and science skills. Finally, players are assessed to monitor their progress. While this was done separately in MAVEN, CAPTIVATE ties each question to an in-game action so that the player can be assessed as they play.

Reemploying Modular Framework

One of the key challenges addressed during the development of MAVEN was the lack of available research on integrating serious game design and instructional design to create a game that was not only fun, but also effective in helping students learn content. As MAVEN was

developed, a modular framework was designed that includes a model and a process for serious game development incorporating game design and instructional design (2). This process, shown in Figure 2, has been reemployed in the development of CAPTIVATE which has greatly decreased the overall startup time for initial game planning and development. By focusing on player, instructional design, and game design characteristics at each stage of the overall development process, the final product is sure to meet the goals of all three.

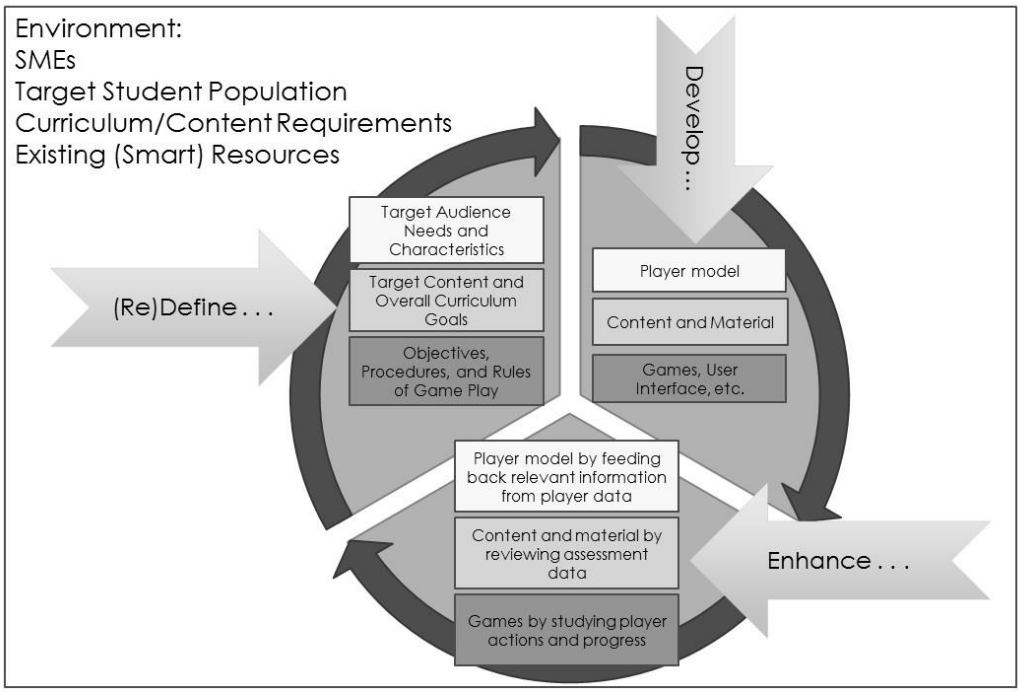

Figure 2: High level process showing the development cycle including player, instructional design, and game design characteristics. Source: (2)

In addition to the process, the model that was developed followed a modular programming methodology incorporating clean interfaces between components. This design methodology was reemployed and expanded in the development of CAPTIVATE. For example in MAVEN, player data and user log in credentials were handled using the same system. In CAPTIVATE, these items are separated as player data is stored online and users log in using existing social media accounts. This off-loads the responsibility to manage user credentials and separates it from user data storage which makes data management simpler. Additionally, the development of MAVEN led to the implementation of a game manager that interfaced with individual game controllers. This allowed for common actions such as updating user score data and switching between games to be handled at a high level which keeping the actual game mechanics code separate. This design has been reimplemented in the development of CAPTIVATE which has resulted in greatly reduced integration times for individual games.

Reinventing Classic Gameplay

During the initial design of MAVEN, the goal was to develop a comprehensive game where the player worked from the beginning to the end of a campaign, improving their mathematics skills

as they played. After examining initial game play data, it was discovered that many players were stopping during or immediately after the initial content module. Even though the content modules were kept short, players were not making it through the content and into the games that followed. It seems that it is difficult to keep students engaged when there are too many constraints directing their learning. This effect mirrors the results from more general studies of online education showing a positive correlation between self-directed learning and online learning outcomes (3). To address this, CAPTIVATE is structured as a series of independent mini-games that can be played in any order. Players can choose the games they play based on their mathematical weaknesses. Then, difficulty increases within each game to help them build their skills. While content is always available, players are not required to complete content modules before progressing to play allowing players to attempt a game and realize on their own that they need to study some supporting content to be successful.

Since story is one of the main components required for a successful game (4), allowing players to play the games in any order presented a problem. When showcasing MAVEN, some of the most positive responses were in response to games that mimicked the game mechanics from well-known games including Battleship (5) and Missile Command (6). Since players are already familiar with the narrative of these games, using the familiar game mechanics removes the burden of providing a narrative within CAPTIVATE. Two of the new games developed for CAPTIVATE are Function Hero, based on the game mechanics of Guitar Hero (7), and MathSweeper, based on the game mechanics of Minesweeper (8).

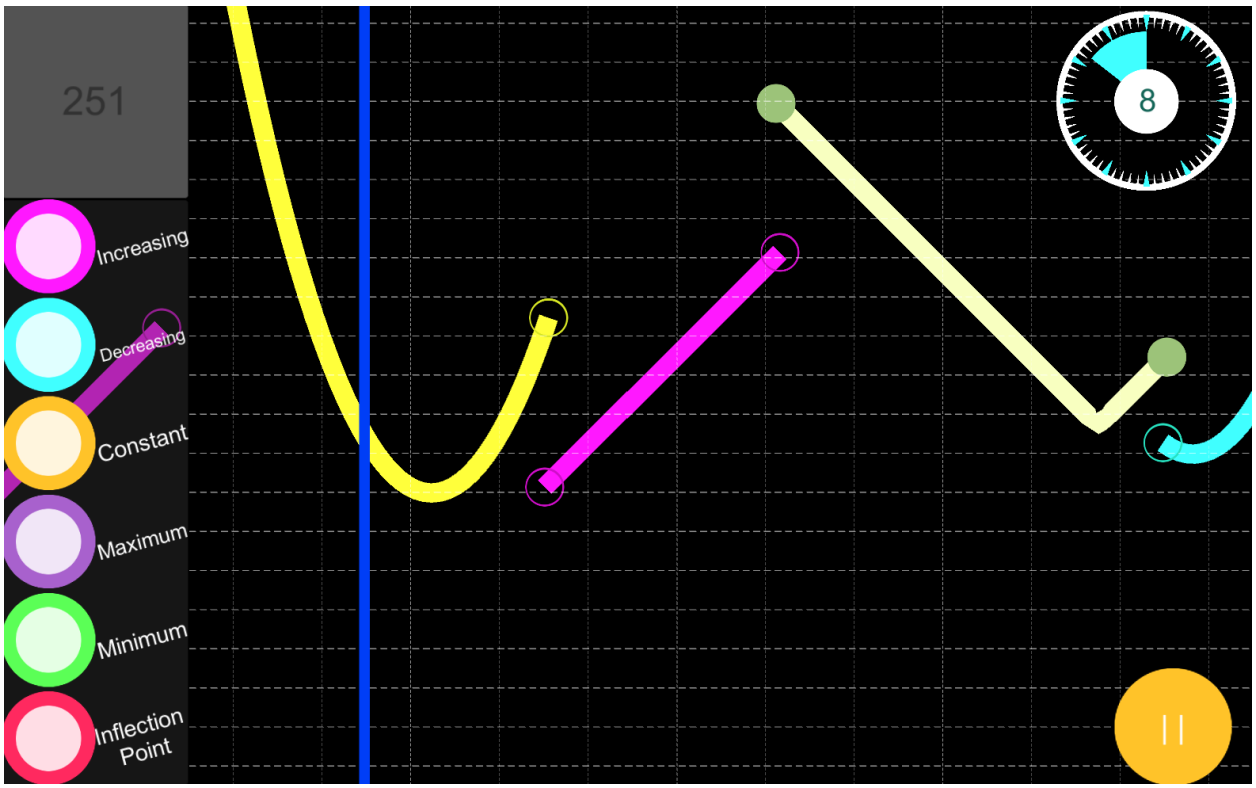

Figure 3: Function Hero. Functions scroll from right to left and players are challenged to classify behavior by pressing and holding the buttons on the left side of the screen.

In calculus, students are asked to classify the behavior of a function based on the values of the first and second derivative of the function over subsets of the domain. Students are asked to identify where the function is increasing, decreasing, or constant and to pinpoint maximum values, minimum values, and inflection points. As important aspect of understanding these behaviors is the ability to identify them from the graph of a function. In Function Hero (Figure 3), the player is presented with a piecewise function that scrolls across the screen from right to left. Instead of playing chords and notes, the player must indicate the behavior of the function as it passes over a line marking a given value in the function's domain. Selecting the correct behaviors results in the accumulation of points which provides immediate feedback on the player's answer.

Another important topic in calculus is learning how to calculate the derivative of a given function. The MathSweeper game (Figure 4) intersperses questions requiring students to find derivatives with game play mimicking the classic Minesweeper game. The player is presented with a gameboard that has mines hidden under certain spaces. As the player clicks the spaces, additional information is provided indicating how many mines are present in adjacent squares. The player is presented with a question requiring them to calculate a derivative each time they click on a square. If they answer the question correctly, they are rewarded with the additional information about the number of mines surrounding that square as well as an increase in score. If

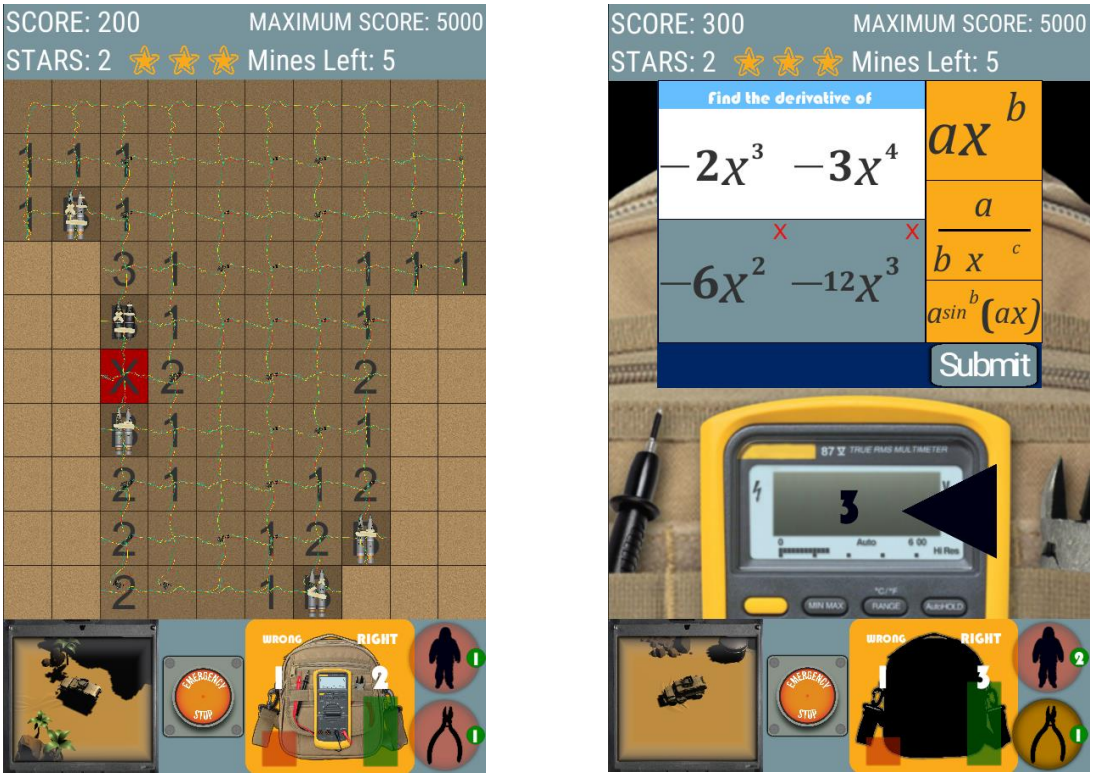

Figure 4: MathSweeper. Players are presented with a game board that has mines hidden under certain spaces. Players are presented with a question, in this case asking them to calculate a derivative, every time they click on a square to reveal additional information about mine locations.

they answer incorrectly, the square is replaced by an “X” and no information is provided. The goal is for the player to clear all squares that do not contain mines and mark the positions of the mines.

Both games previously described are developed for mobile devices and a single round can be played in less than a minute. This means that the games are available for students to practice even if they are away from a computer and only have a few minutes.

Conclusions and Future Work

Building upon the successes and lessons learned from the development of MAVEN, a serious game for precalculus education, a new game designed to help students learn calculus and physics skills has been developed. This new game, CAPTIVATE, reemploys the framework designed to successfully incorporate game, instructional and software design. Additionally, familiar game mechanics are utilized to engage players. CAPTIVATE is developed for mobile platforms and each game is designed to be played in a minimal amount of time so students can use it to learn anywhere when they have a few minutes free.

The next game developed for the project will cover chemistry. This will complete the series of serious games covering all engineering STEM prerequisite courses. In the future, we would like to design and carry out a study to determine the efficacy of the games.

Acknowledgement

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