Game based Cybersecurity Training for High School Students

Ge Jin
Purdue University Northwest
2200 169th St, Hammond, IN 46323, USA
ge.jin@pnw.edu

Manghui Tu
Purdue University Northwest
2200 169th St, Hammond, IN 46323, USA
Michael.Tu@pnw.edu

Tao-Hoon Kim
Purdue University Northwest
2200 169th St, Hammond, IN 46323, USA
Taehoon.Kim@pnw.edu

Justin Heffron
Purdue University Northwest
2200 169th St, Hammond, IN 46323, USA
jheffron@pnw.edu

Jonathan White
Purdue University Northwest
2200 169th St, Hammond, IN 46323, USA
white341@pnw.edu

ABSTRACT

Cybersecurity is critical to the national infrastructure, federal and local government, military, industry, and personal privacy. To defend the U.S. against the cyber threats, a significant demand for skilled cybersecurity workforce is predicted in government and industrial sectors. To address this issue, National Security Agency and the National Science Foundation jointly funded GenCyber program to stimulate the K–12 students' interest in the cybersecurity field and raise their awareness of cybersecurity and safe online behavior. Purdue University Northwest has successfully launched four GenCyber summer camps in 2016 and 2017 to 181 high school students, with 51.3% underrepresented minority ratio (Africa American and Hispanics), and about 2:1 male to female ratio. We delivered GenCyber summer camp activities in the format of game based learning and hands-on labs. The use of game-based learning in the camp was an excellent platform to teach concepts of cyber security principles. For example, in Cyber Defense Tower Game, students need to protect their servers from the different types of cyber-attack. They need to select the correct type of defense to stop each wave of cyber-attack. As the students advanced through the game, combinations of the different attacks would come faster, making it more difficult for the students to defend their servers. This game was well received by the students, support staffs, instructors, and site visit team. Learning through these activities provided high school students with an immersive, learner-centered experience, which has been proven very effective on cybersecurity awareness training and practical skill acquisition for learners from diverse backgrounds. Further analysis of survey data revealed that the gamification of cybersecurity education to raise students' interests in computer science and cybersecurity was more effective in male high school students than in female students.

CCS CONCEPTS

• Social and professional topics → Computing education → Computing education programs → Computer science education; • Social and professional topics → Computing education → K-12 education; • Applied computing → Computers in other domains → Personal computers and PC applications → Computer games

KEYWORDS

Cybersecurity; Cybersecurity education; Game base learning

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1 INTRODUCTION

With the recent high profile cybersecurity incidents targeting Sony Pictures, Target, Anthem and the massive OPM government data breach that followed, cybersecurity has become a top priority for the U.S. government. The U.S. government and major legislative proposals have been passed to enhance U.S. cybersecurity and new government agencies have been proposed to combat cyber threats. Cybersecurity is a shared mission between government and industry, because a large portion of the national cybersecurity infrastructure is in the private sector. Over the past few years, millions of sensitive data records have been compromised and a large number of frauds have been committed, especially in financial and healthcare sectors [1,2]. Such security breaches not only result in substantial financial losses, but also greatly hurt the confidence of customers, business partners and stakeholders [3].

Cybersecurity workforce development is the key to assuring that the nation has adequate security measures to protect and defend information and information systems. However, a global shortage of "1.8 million cybersecurity professionals by the year 2022" has been estimated [4]. According to the U.S. Bureau of Labor Statistics, the growth rate of jobs in information security

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is projected to be 37% from 2012–2022, and at the same time more than 209,000 cybersecurity jobs in the U.S. will be unfilled every year. The increasing demand for cybersecurity professionals from both government and private sectors makes it a critical mission for higher education institutions to attract and train next generation of cybersecurity workforce and citizenry who are capable of advancing national economic prosperity and security. The U.S. Congress has urged that it is critical to develop high-quality educators to expand cyber education at early age [5]. Expanding cybersecurity education to high schools has been highly advocated, as opinioned by a business leader in The Washington Post, "the key to training more cybersecurity experts is exposing students to STEM education — science, technology, engineering and mathematics — as well as adding some cybersecurity training in high school". To increase K-12 students' interest in cybersecurity and the diversity of cybersecurity workforce, the National Security Agency (NSA) and the National Science Foundation (NSF) have jointly funded more than 300 summer camps to K–12 students and teachers across the nation for the past 3 years [6].

Purdue University Northwest (PNW), a NSA/DHS designated National Center of Academic Excellence in Cyber Defense Education, has successfully launched four GenCyber summer camps for 181 high school students with 51.3% of underrepresented minority (Africa Americans and Hispanics) ratio. PNW GenCyber camp developed innovative game based cybersecurity education modules to provide high school students with hands-on activities in an immersive learning environment. We developed virtual reality (VR) 3D games, robotic programming games, and practical ethical hacking and cyber forensics labs based on simulated cases for cybersecurity training for high school students. The game based cybersecurity education is extremely beneficial to the future cybersecurity workforce by exposing more high school students to the cybersecurity education pathway at a time when they are making decisions regarding higher education. The innovative pedagogical methods and age appropriate game based learning curriculum, has made cybersecurity concepts more accessible to students of varying ability levels. This was supported by the post camp survey conducted for 154 participants.

2 RELATED WORKS

Research indicates that students receiving computer education in high school are 8 times more likely to major in a computer degree, while in the last 20 years; enrollment in computer education courses has seen a dramatic decrease at the high school level [7]. In addition, student participation is unrepresentative of national demographics. These statistics indicate that the key to developing more graduates in the cybersecurity field is establishing a meaningful pathway earlier in the educational process. A primary challenge to achieving this goal is the lack of age-appropriate cybersecurity curricula implemented with pedagogical methods that are most conducive to learning at the high school level [5].

Studies have shown that students learn only 20% of what they hear and read, but can learn 90% of what they have practiced [8]. Traditional teaching uses lectures as the major vehicle to deliver scientific knowledge and technology to learners, which has proven to fall short for learners. Learners at the high school level experience greater cognition if they are given opportunities to actively engage in classroom activities that support the development of critical thinking and problem solving skills. Therefore, there is a critical need for an innovative curriculum and pedagogical methods in the area of cybersecurity education.

The advance of technologies, high-speed connections, and the pervasiveness of mobile devices, have enabled various computer based pedagogical methods. One of the emergent and rapidly mutating forms of computer-based learning is "game based learning." As its name suggests, computer game allows learners to be immersed in an artificial or simulated game environment while experiencing it as real. Game based learning include virtual reality games, web-based games, multi-user virtual environments (MUVEs), massively multiplayer online games, and simulations [9]. Till date, applying game based learning instructional method to cybersecurity education is limited [10].

3 METHODOLOGY

The primary goals of NSA/NSF GenCyber program are: 1) increase interest in cybersecurity, 2) raise general awareness of cybersecurity and help all students understand appropriate and safe online behavior, and 3) increase diversity in the US cybersecurity workforce. As described in the introduction section, PNW GenCyber camp recruited 51.3% of underrepresented minority high school students, and met the goal of increasing diversity of summer camp participants.

To raise general awareness of cybersecurity and safe online behavior of high school students and increase their interest in cyber security, we developed game based cyber security learning modules to meet the GenCyber program goals. The topics of cybersecurity education games were selected in the following areas:

1. Social engineering and information security: Social engineering is the art of manipulating people so they give up confidential information, and social engineering scams such as phishing email have been extremely effective in security attacks. PNW GenCyber camp implemented a 3D VR game to simulate Piggybacking, Tailgating, and Mantrap in a security enhanced office environment to raise general awareness of social engineering scams.

2. Secure online behavior game: Secure online behaviors include identifying phishing emails and appropriately handling them, distinguish between trustworthy web links and insecure links, handling phony phone calls, and protecting personal information. A 3D VR secure online behavior game was developed to simulated high school computer lab and student's bedroom environment. The secure online behavior game allows students to appropriately handle email messages, text messages,

web links and phone calls, using various computing devices such as school computers, mobile phones, laptop computer, and networked game console.

3. Cyber Defense Tower Game: Tower defense game is a subgenre of strategy game to defend a player's territories or possessions by placing defensive structures on or along their path of attack [11]. A Cyber Defense Tower Game was created to allow students to protect their virtual computer server from the different cyber-attacks by applying GenCyber first principles and cybersecurity knowledge. Students need to select the correct types of defense tower to stop each wave of cyber-attacks. As the game progresses, the combinations of the different cyber-attacks would come faster and will make it more difficult for students to defend their servers.

4. 2D GenCyber Card Game: The GenCyber card game is a computerized version of physical GenCyber card game. Physical GenCyber card game requires two players to play the game in face-to-face mode. The computer based GenCyber card game is a single-player version of the GenCyber card game, which allows the students to play the card game by themselves at any convenient time.

3.1 3D Virtual Reality Game Development in Unity3D

Social engineering and secure online behavior game were developed in Unity3D game engine. Both games can be classified as 3D Role-Playing-Game (RPG) genre. The development of 3D RPG cyber security game consists of three major technical components: (1) 3D character and game environment modeling, (2) animation of the 3D game characters, and (3) scripting/programming of the interaction between game characters and dynamic behaviors.

The 3D characters of the game were created from Adobe Fuse software. Instead of modeling a 3D character from scratch, Adobe Fuse allows a user to assemble a 3D character from more than 20 base characters and further customize it into a unique character with different weight, height, skin tones, and texture.

The 3D character from Adobe Fuse was transferred seamlessly into Mixamo software. Mixamo will automatically rig the 3D character and provide hundreds of different motion clips that can be used to animate the character. We selected essential motion clips (such as idle, walk, run, talk, sit, and stand) for each character and export the animated 3D character to Unity3D game engine.

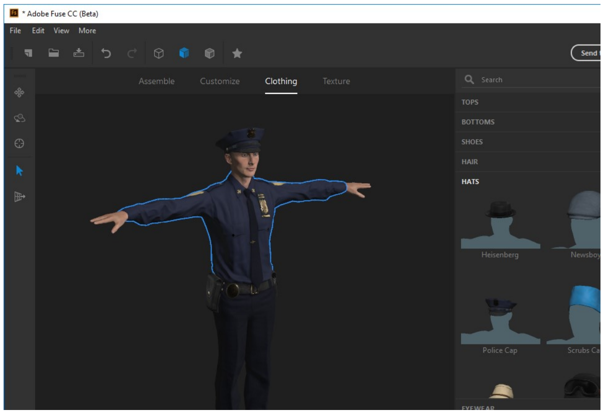


Figure 1: 3D Character Modeling and Customization in Adobe Fuse.

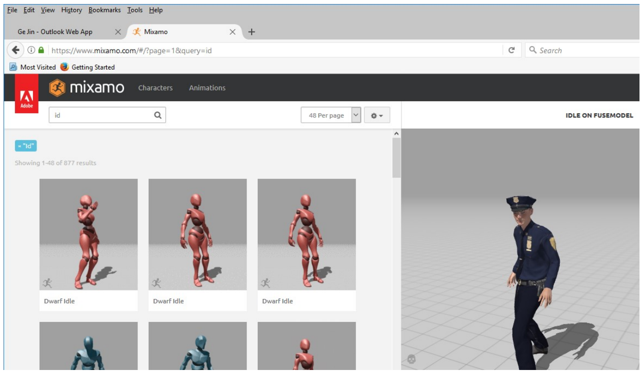


Figure 2: Character Animation in Mixamo.

The game environment was modeled mostly using the loyalty-free 3D assets from Unity Marketplace. Several 3D assets that related with social engineering and secure online behavior games were modeling using Autodesk 3D Max and Maya software. The behaviors of the 3D game characters were implemented by programming Unity C# script for each 3D character and dynamic assets in the game environment.

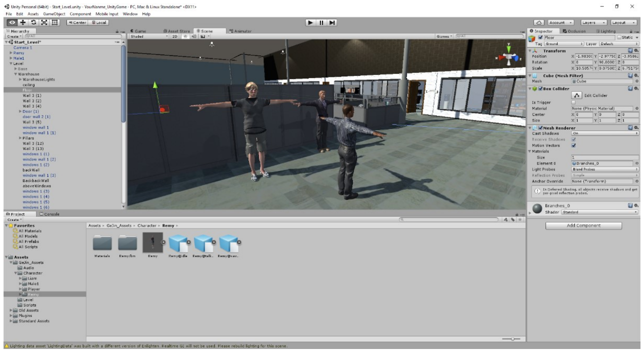
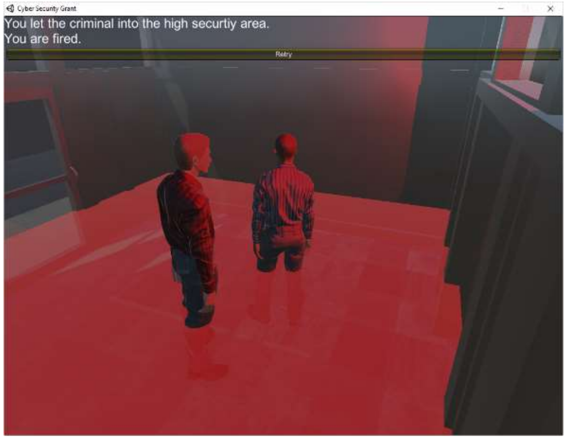


Figure 3: Programming interactions and dynamic behaviors using Unity C# script.

The flowing figures were captured from social engineering game and secure online behavior game.



You let the criminal into the high securtiy area.
You are fired.

Figure 4: **3D Social Engineering Game.**

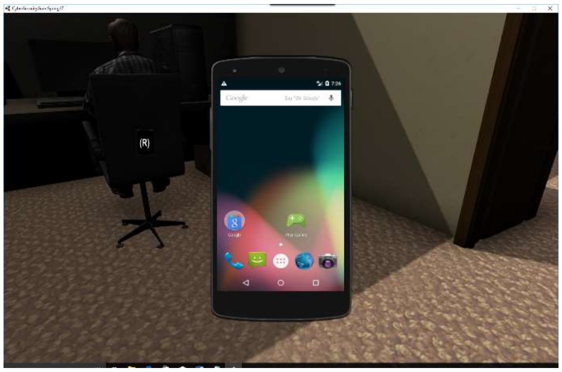


Figure 5: **3D Secure Online Behavior Game.**

3.2 Development of Cyber Defense Tower Game in Unity3D

The cyber defense tower game was implemented on top of Tower Defense Toolkit (TDTK) developed by Song Tan [12]. TDTK is a C# coding framework for the easy construction of Tower Defense games. TDTK comes with a bundle of scripts that can be adjusted to fit a variety of Tower Defense gameplay scenarios. The toolkit is designed custom models and art assets, and user can integrate their own art assets to make unique Tower Defense game. We have created 7 unique cyber-attacks (Fig. 6) and 6 cyber defense towers (Fig. 7).

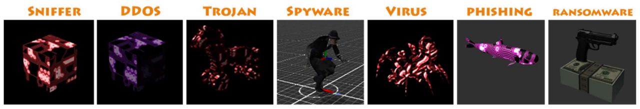


Figure 6: **Cyber-Attacks in Cyber Defense Tower Game.**

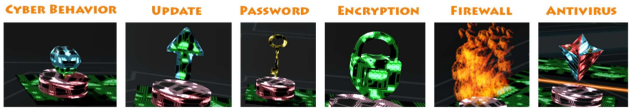


Figure 7: **Defense Towers in Cyber Defense Tower Game.**

One limitation of TDTK is that there are only two types of attacks: ground, air and three types of defense towers: ground, air and hybrid. It's impossible to use the built-in attacks and defense towers to simulate the cyber-attacks and defenses. We have customized the Tower Defense Toolkit to include 7 additional attack types (Virus, Phishing, Trojan, Spyware, Ransomware, DDoS, and Sniffer), and 6 additional defense towers (Antivirus, Password, System Update, Secure Cyber Behavior, Encryption, and Firewall). Some defense towers will defend single type of attack, while other defense towers can defend multiple attack types. For example, the Antivirus tower will defend against Virus, Trojan and Spyware. In addition, certain type of attack can be defended by multiple defense towers. The Sniffer attack can be defended by Password tower and Encryption tower. Cyber Defense Tower Game contains three difficulty levels: tutorial, intermediate and competition level. Fig. 8 is the tutorial level and Fig. 9 is the competition level.

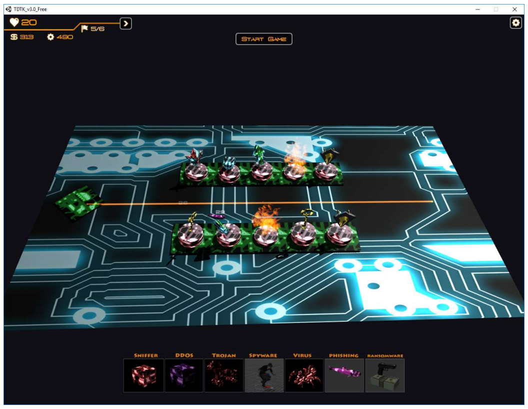


Figure 8: **Tutorial Level in Tower Defense Game.**

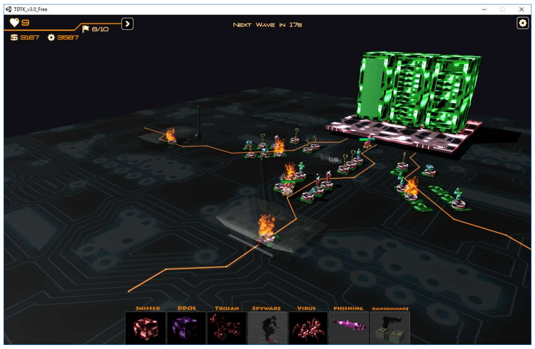
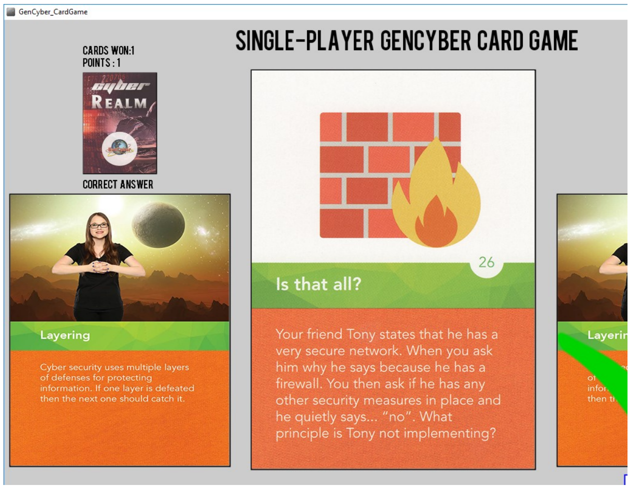


Figure 9: **Competition Level in Tower Defense Game.**

3.3 Single-player GenCyber Card Game

The single player version of GenCyber Card game was developed to enhance the students' understanding of 10 Cyber Security First Principles. The original card game was designed and created by Dr. Vincent Nestler at California State University San Bernardino [13]. The computerized GenCyber card game was created by scanning the cards and uploading the images into

Processing programming environment. The site team observed students playing this game during the down time at camp and some students were even creating "cheat sheets" so they could beat their friends' times.



Cyber security uses multiple layers of defenses for protecting information. If one layer is defeated then the next one should catch it.

Your friend Tony states that he has a very secure network. When you ask him why he says because he has a firewall. You then ask if he has any other security measures in place and he quietly says... "no". What principle is Tony not implementing?

Figure 10: Single-player GenCyber Card Game.

4 RESULTS

Purdue University Northwest has successfully launched two 1-week summer camps in June 2016, and another two 1-week summer camps in June 2017. Each GenCyber camp day consists of four 90-minutes sessions; two 15-minutes group discussions, a 60-minute lunch break, and two 15-minutes mini breaks. The day activity will start from 9:00am and ends at 4:30pm. During the 1-week summer camp, each student participated in activities mentored by a team of PNW faculty members and student assistants. The GenCyber team includes 4 faculty members and their roles are listed below: 1) Dr. Ge Jin has 9 years of college teaching and research experience in computer graphics, visualization, animation, with teaching experience in fundamentals of information assurance for CIT program. 2) Dr. Michael Tu has 11 years of college teaching and research in cybersecurity and digital forensics, certified Ethical Hacker, Certified Pen Tester, Certified Hacking and Forensics Investigator, and Certified AccessData Computer Examiner. 3) Dr. Tae-Hoon Kim has 5 years of college teaching and research experience in computer networks, network security and taught computer networks, network security, network design & administration courses at both undergraduate/graduate levels. 4) Dr. Keyuan Jiang has 20 years of college teaching experience in software programming with extensive project management and student advising experiences.

Total of 181 high school students attended the summer camps with 51.3% were underrepresented African American and Hispanic students. The male to female ratio was 2.12 to 1 (Table 1). The students were exposed to cybersecurity first principles and cybersecurity awareness by playing various cyber security computer games during the first two days. About 25 students in one classroom have competed for 3D Secure Online Behavior game, Cyber Defense Tower game and Single-player GenCyber Card game. We picked one winner from each competition and awarded the winner with a small gift on the last day of the summer camp.

Table 1: Male to Female Ratio of Camp Participants

Year	Gender	Numer of participants
2016	Male	60
	Female	26
2017	Male	63
	Female	32
Total		181

The post-camp survey was conducted at the last day of the summer camp. A 5-point Likert scale was used to measure the student's satisfactory rate of camp activities and experiences ranging from 5 (strongly agree) to 1 (strongly disagree). The post-camp survey of 154 camp participants indicated that game based learning for cybersecurity has enhanced student's knowledge in cybersecurity, and understanding of the cybersecurity first principles, and educated a digital citizenry with security awareness, and motivated them to pursue higher education and careers in the field of cybersecurity.

Table 2: Post-camp Survey Questions and Results

Post-Camp Survey Questions	Rating
I enjoyed learning about computer science	4.36
I would like to learn more about computer science	4.22
I enjoyed learning about cybersecurity	4.27
I would like to learn more about cybersecurity	4.05
The teachers/faculty in this program made me more interested in cybersecurity	4.20
I know what cybersecurity means	4.27
I know more about cybersecurity than I did before this camp	4.36
I know more about computer science than I did before this camp	4.26
I am more comfortable learning cybersecurity concepts now	4.08
I know more about information security than I did before this camp	4.29
I can explain why cybersecurity is important	4.18
Overall this camp was a good experience	4.46
I am glad I attended this camp	4.46
I would like to attend more camps like this	4.17
My opinions and ideas were respected in this camp	4.32
I found the camp activities interesting	4.22
I liked interacting with the teachers at this camp	4.28

The authors further analyzed the survey data to investigate the gender difference in game-based learning. Hypothesis testing for two population means with unequal variance (T-Test) was used to test gender difference for each survey question. The result of hypothesis testing shows that: there are significant differences between male and female students' impression about the camp activities in survey question 1 and survey question 16. It can be interpreted as: the male students thought the game based learning camp activities were more enjoyable and interesting than female students.

5 CONCLUSIONS

In this paper, we introduced an innovative game based learning method for cybersecurity education. Four computer games were developed to educate social engineering and information security concept, secure online behaviors and cybersecurity first principles. The use of game-based learning in the PNW GenCyber camp was an excellent platform to teach concepts of cybersecurity principles and secure online behaviors. This approach is beneficial to the future cybersecurity workforce by exposing more high school students to the cybersecurity education pathway at a time when they are making decisions regarding higher education. The game based learning method was well received by the students, support staff, instructors, and site visit team. This was also supported by the post camp survey conducted for 154 participants with average rating of 4.26 out of 5. To investigate the gender difference of game-based learning, hypothesis testing for two population means with unequal variance (T-Test) was conducted to test gender difference. The hypothesis testing result indicated that the male students thought the game based learning activities were more enjoyable and interesting than female students.

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