Development of a Virtual Reality Educational Game for Waste Management: Attack of the Recyclops

Dr. Fadi Castronovo, California State University, East Bay

Dr. Castronovo is an assistant professor of engineering at the Cal State East Bay's Construction Management program, part of the School of Engineering. Currently, Dr. Castronovo has started the STEM Educational Gaming Research Group. The group is composed of undergraduate students from computer engineering and science, construction management, and other STEM disciplines. The goal of the STEM Educational Gaming Research Group is to enhance instruction in the engineering department, support the students in gaining competitive technical and problem-solving skills, stimulate student's involvement in research, and promote new internal and external research. His previous research efforts have focused on the NSF-funded Virtual Construction Simulator (VCS) research project. The VCS is an educational simulation game design to support college construction engineering students in developing complex problem-solving skills. To have a strong assessment of the educational value of the game, he pursued a minor in Educational Psychology at the Educational Psychology Department at Penn State. This experience allowed him to gain invaluable knowledge in the field of cognitive, metacognitive, and motivation education.

Dr. Semih Yilmaz, California State University, East Bay

Mr. Akarsh Rao, Immersive and Interactive Research Group

Mr. Walter Condori Jr., California State University, East Bay

Karan Monga, STEM Educational Gaming Research Group

Karan Monga is an international student in his second year pursuing a degree in Computer Science. He is a research assistant in the STEM Educational Gaming Research Group. He is in charge of game development and programming. He also led the development of the Cal State East Bay virtual campus, by leveraging several modeling tools. Through the educational simulation game, he aims to educate college students about the importance of waste management and sustainability by letting them inside the virtual world. He hopes to become a full-time game developer after he graduates.

Miss Hadiseh Gooranorimi, California State University, East Bay

Hadiseh Gooran is a graduate student in Interaction Design at California State University, East Bay. She is a research assistant in the field of Immersive and Interactive Research. While being extremely passionate about the research in STEM educational system, Game-based learning and VR/AR technologies, she also is one of the most involved student in this field. Her proficiency is in Character Design and 3D-Modelling and Animating, and she has a major role in this project, providing a realistic experience within the virtual environment.

Dear Editor and Reviewers,

We would like to thank you for your reviews and suggestions. We have addressed the reviewers' suggestions to the best of our capabilities and worked on improving the paper's quality. We tried to reach out to the editor with questions related to our submission, as we wanted to make sure that we had addressed all of the issues, especially the length of the paper. Please see the email correspondence in the following page. Unfortunately, we did not receive a response as of March 18th 2018, and we hope to receive directions after this submission.

Thank you very much and please email us for any questions.

Best,

Fadi Castronovo, Ph.D. and Semih Yilmaz Ph.D
California State University East Bay

Fadi Castronovo <fadi.castronovo@csueastbay.edu>

URGENT: ASEE Work-in-Progress Paper #21140 Questions

1 message

Fadi Castronovo <fadi.castronovo@csueastbay.edu>

Tue, Mar 13, 2018 at 8:18 PM

To: schilling@msoe.edu, Semih Yilmaz <semih.yilmaz@csueastbay.edu>

Dear Editor,

We greatly appreciate your helpful and encouraging comments on our paper # 21140 for the ASEE 2018 Annual Conference. We are especially grateful for your suggestions for future research directions. We will be incorporating your suggestions as we progress on this project.

In terms of format related issues, we apologize if we misunderstood the guidelines. In the author's kit, the guidelines are either for draft paper or full paper (no guidelines category for 'work-in-progress'); therefore we had assumed our paper was subject to the draft paper requirements. Also, we are aware that there are a total of ten illustrative items (tables and figures) in this paper and all except one are based on our study. These items were meant to summarize and illustrate various parts of our project that are otherwise lengthy or difficult to describe. However, we consolidated the paper to move all these items under APPENDICES, so that the body piece is 9 pages. We also reformatted and proofread again to align the paper with ASEE standards. Please see attached document for the updated document.

Hoping these changes addressed your points, please let us know if you need us to make any other changes, modifications, or have any other comments, suggestions.

We look forward to meeting you at the conference.

Best,

Fadi Castronovo, Ph.D. and Semih Yilmaz Ph.D.
California State University East Bay

Castronovo et. al - Attack of the Recyclops - Editted.docx

1046K

**Work-in-Progress: Development of a Virtual Reality Educational Game for
Waste Management: Attack of the Recyclops**

1. Introduction

Negative impacts of human consumption and waste on the natural environment is a long-researched topic, which led the international scientific confidence in the human-influenced climate change to reach its highest point (95-100% likelihood) in 2014 [1]–[6]. A significant reason for this impact is the fact that much of the waste ends in landfills, rather than recycling facilities. U.S. Environmental Protection Agency (EPA)'s most recent report shows that more than 50% of the 259-million-ton municipal solid waste (MSW) goes to landfills [7]. This waste, in turn, rots and produces the greenhouse gas known as methane. Methane is a powerful contributor to the progression of global warming since it can amplify the greenhouse effect of carbon dioxide by 21 to 25 times [8]. To combat this effect, California, for example, has enacted Assembly Bill no. 1826 in 2014 [9]. This bill requires organizations to establish waste management facilities; this also reflects onto universities and colleges. The inclusion of universities in this bill is following the landmark 2001 decision of EPA to hold higher education institutions responsible for their environmental impact on an equal footing with other commercial and governmental institutions [10], [11]. Universities are not only among the many institutions that contribute to energy, water or solid waste, but their ecological influence goes beyond the campus through the impact of their education [12], [13].

The facilitative role universities can (and must) play in environmental sustainability has repeatedly been emphasized by scholars [14]–[19]. Many examples have been reported regarding the institutional transformation universities have undertaken to reduce their waste and achieve a higher degree of campus sustainability, and educational components are integral to these transformations [14], [20]–[31]. Arguably the most significant part of the campus community through universities actualize their sustainability potential is the body of students. Students are the key multipliers for the impact any environmental education initiative can hope to achieve in greater society. Having the most significant share within the university population, students alone continue to be the chief source of human consumption and waste in any campus. Figures from 2015-2016 suggest more than 50% percent of students consumed food on campus, with a record total of 1.6 billion year-round visits to on-campus dining facilities. Hence, the monumental impact students' environmental learning experience engenders is likely to be observed in the immediate campus setting before it facilitates change within the larger local and regional populations.

Among the various educational initiatives that are proposed to target students' environmental learning and proper waste disposal [24], [29], [32], application-based environmental learning has been emphasized as an area requiring specialized research within environmental education for optimal learning outcomes [33]–[36]. Educational games are one form of application-based learning strategies that may have the pedagogical potential to enhance environmental education among the current generation. The profusion of digital technology over the past decades has produced a new wave of students who prefer to actively use technology, collaborate, and learn through experiential activities [37]–[41]. Previous research in the fields of visualization, multimedia learning, and gaming education has illustrated the immense educational potential that educational games have in introducing a wide variety of knowledge, problem-solving skills, and behaviors in students from kindergarten to university graduates. On the other hand, recent innovations in digital technology – such as Virtual Reality – is likely to

expand this potential to new frontiers, where the distance between the classroom and real-life or ‘field’ experiences diminishes. Most analysts agree that we are currently in the middle of the proliferation and mainstreaming of this once-fringe platform [42]–[44]. Virtual reality headsets and display systems, and augmented reality headsets are being leveraged for their potential to enhance the user’s ability to solve problems and shape their behavior. Moreover, several studies indicate the advantages VR technologies might have in terms of learning outcomes [45]–[47]. Therefore, this study focuses on learning proper waste disposal by utilizing innovative educational technology such as virtual reality educational games. Based on the value that virtual reality possesses, the research team has set the objective to evaluate the potential effect that a virtual reality educational game has on learning and behavior of waste management.

2. Background

2.2 Environmental Education and Students’ Involvement in Campus Waste Management

Research on the determinants of environmental behavior indicates that several external or societal [48]–[50] and internal or psychological factors [51], [52] are conjointly influential on individuals’ pro-environmental behavior [33], [53], [54]. In addition to social norms, values, attitudes [51], [54]–[57], educational background, more specifically, knowledge level pertinent to environmental protection, has been suggested to be a significant predictor of pro-environmentalism [33], [58], [59]. To maximize the contribution of environmental education to desirable behavioral outcomes within the greater conservation efforts (such as replacing single stream waste management systems with multi-stream or source-controlled systems), research has urged attention to several different aspects of education; most notably on learning processes [35], [36], actionable knowledge creation and its application [33], [58], [60] as well as the incorporation of constructivist, informal, and free-choice settings into educational systems [61]. An indication of these studies is that understanding and leveraging the internal mechanisms that facilitate or inhibit the translation of attitudes into conation is crucial for any educational intervention aimed at significant behavioral change. There are multiple approaches students can take on campus to tackle the growing issues of food waste. Recently, the University of Northern British Columbia implemented a sustainable campus campaign where students mapped out all the designated waste disposal containers around the campus grounds [28]. This method allowed for the tracking of how waste is distributed around the university and observed students’ behavior patterns when disposing of their waste. Another successful waste reduction and management campaign was launched by students and faculty in New Zealand University. A key factor for the campaign success was the funding provided to engage students interested in waste management and reduction [62]. The implications of these studies are aligned with others in the field that suggest interactive [30] and creative [23] learning experiences that adopt social marketing techniques [24], [29], [32] might increase students’ involvement in campus-wide waste management initiatives.

2.3 Educational Gaming

Constructivist learning theories imply that instructors must develop environments where students learn by actively engaging with the environment through the use of different types of material [63]. Educational research has placed particular focus on multimedia learning to provide experiential learning environments to students [64], [65]. Mayer’s [65] cognitive theory of

multimedia learning defines learning as the process of “building mental representations” (p. 2) and constructing knowledge from words and pictures [65]. One example is educational simulation games, which have become a subject of research in education. Simulation games allow the student to learn by interacting with a repeatable and unique environment [66]. Educational simulation or serious games are being analyzed for their ability to support learning by providing a close to realistic environment for problem-solving through visualization, exploration, and immediate feedback [67], [68]. Serious games can be defined as computer games that can be used for training or educational purposes, while still engaging the user in a fun experience [69]–[71]. Because of their educational benefits, serious games are being applied even in higher education [72]. Several studies approve that simulation games help students develop awareness of real-world issues and achieving learning objectives [73]–[76]. Presently, there are numerous games that concentrate on sustainability and waste management. For example, City Rain and Green World which are sustainable city builder games; PowerUp a game on energy quests; CO2FX a serious game; Plant It Green a sustainable builder game [77]. While there are several serious games about sustainability and recycling, there is an apparent lack of games that specifically focus on waste management on university campuses.

2.4 Virtual Reality and Education

One example of media that can engage students in experiential educational experiences is virtual reality (VR). Increasing research in VR is focusing on its ability to promote spatial presence and immersion of the user inside a virtual environment [78]. Through the use of VR, students’ engagement and motivation in learning are enhanced [45], [79]. For example, at the University of Iceland, a program called “Innovation Education” provided VR experiences to their engineering students, allowing them to understand the concepts in their textbooks [47]. The benefits they found from this study were that students not only gained the basic textbook knowledge but experiential knowledge as well. In this virtual environment, the students were able to see and experiment with the software and use trial and error to solve problems. They were able to test their products in the simulated world, and gain knowledge and express their creativity with their projects. Based on these benefits, VR can be a suitable learning environment that simulates the waste cycle and educate students. VR offers an opportunity for students to emotionally connect with how their waste affects the environment [46]. In VR, students can interact with environments allowing them to make an emotional connection to the environmental consequences of their choices. According to Riva et al. [46], VR can provide a strong mental connection with the presented content because of its immersive capability. Therefore, the immersive nature of VR has the potential to bring students to consciously empathize with the process of waste disposal. Controlling the process of waste management through a virtual medium could allow for a unique user content experience that is unparalleled in conventional audiovisual implementations. Once students can make an emotional connection with the environmental consequences of their actions, students might be more likely to dispose of their waste properly. Based on the value VR possesses and the existing research gap, the research team, has set the objective to evaluate the potential effect that a VR educational game has on learning and behavior.

3. Research Goal

The continuous advances in educational technology and research have illustrated the potential for gaming technology to enhance the learning process and increase learner engagement. In particular, research has illustrated that educational gaming can engage students in acquiring a wide range of cognitive processes, ranging from basic remembering to complex problem-solving. Based on these advances, the research team wanted to evaluate the pedagogical potential of virtual reality educational games on pro-environmental behaviors. In particular, the research team set forward the goal of developing an educational virtual reality game, designed to enhance the learning of responsible waste management. The research and design team was composed of two faculty and three undergraduate students. The undergraduate students were lead points on the design and development of the game, the role of the faculty was instruction and guidance throughout the design process. With this presented work the research team will share their design experience in developing the virtual reality educational game *Attack of the Recyclops*. In addition to the design and development of the game, the paper will also share the efforts in design educational assessment material necessary to evaluate the learners' educational gains.

4. Instructional Design of the *Attack of Recyclops*

The research team has developed an educational virtual reality game, *Attack of the Recyclops*, to analyze its impacts on the learning and pro-environmental behavior of undergraduate students. The learning objective the research team put forward, is that at the end of the gameplay the player will learn how to choose the correct disposal avenue for different types of wastes. The VR headset that the team will use is the Oculus Rift. With this headset, the researchers will place the player within a virtual campus, and the player will be able to explore the campus and learn the importance of waste management. The ADDIE model framework for instructional design was utilized to guide the design and development of the game (see Figure 1). The ADDIE model framework was designed by the Center for Educational Technology at Florida State University for military training and has become a commonly used model for instructional design [80]. ADDIE is an acronym for each of the instructional design phases: *analysis, design, development, implementation, and evaluation* [81]. As mentioned earlier, the purpose of this paper is to report the efforts in the analysis, design, and development phases of the game. The following subsections describe such efforts.

[Insert Figure 1]

4.1 Analysis

4.1.1 Audience and Environment

Educational games have the capacity of being implemented in various environments (such as desktops or mobile devices) and target a variety of audiences. For *Attack of the Recyclops* game, the research and design team chose the college classroom as its main delivery environment. In particular, the team chose the Visualization and Immersion Classroom at California State University East Bay (CSUEB). The Visualization and Immersion Classroom (VIC) is suited for the delivery of large-scale educational interventions (see Figure 2). The VIC is a computer laboratory equipped with 48 high-end computers capable of running the latest visualization software. The VIC is also equipped with 10 Oculus Rift, capable of rendering virtual environments in real-time. Based on the environment, the target audience of the game will

be undergraduate students. In particular, the game was designed for first-year undergraduate students and transfer students joining the CSUEB campus. The research team selected this student population to maximize the transfer of the desired learning and behaviors to incoming students and have a long-lasting effect on their academic life and environmental behavior at CSUEB. To target these students, the research and design team has developed the game to immerse the users in a virtual recreation of the CSUEB campus. By immersing the students within the virtual campus, they will be able to easily transfer the learned behavior in the real-life campus.

[Insert Figure 2]

4.1.2 Learning Objectives

According to Cannon and Burns, an essential step in the design and development of educational games is the definition of learning objectives [82]. The authors argue that developing learning objectives is necessary to drive the development of the game's assessment measurement or methodology. By establishing learning objectives, an instructor can set a path of the measurable outcomes that the learner will achieve by playing the game. To develop the learning outcomes for *Attack of the Recyclops* game, the team, by leveraging previous research, leveraged the revised Bloom's Taxonomy of educational objectives [82]–[85]. In the first version of the taxonomy, Bloom set three domains for the assessment of learning objectives: cognitive, affective, and psychomotor [83]. In the revised version of the taxonomy, the cognitive domain ranges from lower to higher order thinking skills (see Figure 3) [84].

[Insert Figure 3]

Based on the taxonomy the team has set identified three levels of desired thinking skills: remembering, understanding, and applying. Within these levels the team has selected the following action verbs: identifying, explaining, and executing. Each of these action verbs is aligned with a level of thinking skills; for example, identifying is aligned with the remembering thinking skills, which is a lower order thinking skills. Based on these levels the team has set forward the following learning objectives for the *Attack of the Recyclops* game, (see Table 1).

[Insert Table 1]

4.2 Design

4.2.1 Game Story and Mechanics

Schell identifies four basic components for a game: mechanics, story, technology, and aesthetics [87]. Therefore, before the start of the game development, the team designed each of the four components set forward by Schell. The technology and aesthetics components of the game are discussed in the following section. The story of the game was set by the designers of the game, and it will be introduced to the player through a narrative voiced over a sequence of pictures illustrating the story. The narrative for the introduction is as follows: *"We all remember the day that the bins revolted on our campus. It happened when an engineering student threw a plastic bottle in the composting bin. The ground shook and a loud roar came from the bin. Then, the bins from all of the campus revolted. They grew and started to attack by throwing all of their*

trash back at us. Now we all live in fear of the bins, and we wish we could have been more responsible with our trash. However, now you came along, THE CHOSEN ONE, and only you can save us and save the bins. We are counting on you...”. Based on the story, the design team set forward the game mechanics. The game will begin by introducing the story, giving the necessary background to the user. Then a small video tutorial is going to illustrate how to interact with the game, by listing the different commands that the user can use to navigate and throw their “trash”. Then, the user will be transported to a virtual version of the CSUEB campus and will be presented with their main weapon a slingshot. The user will be challenged with the main quest of feeding the monster bins with the correct trash. As the user walks around campus, they will be able to collect trash and throw it at the monsters around the campus. Once the bin is fed the correct trash, they will return their natural form. The location of the monster bins was chosen based on the actual location of bins on campus, providing a chance for the user to transfer their skills to the real-life campus. Once the users fed all of the monsters around campus and transforming them, the game will end. Based on the game mechanics the team then developed a game scene structure (see Table 2). The main game scene will include several aspects of the game mechanics, such as picking up the slingshot and the trash to transform the trash bins back to normal. The purpose of each of the scene is included in the table.

[Insert Figure 4]
[Insert Table 2]

The game was designed to reflect the current waste management practices on campus. Currently, the campus collects waste through three streams, recycling, compost, and landfill. The design team developed the monsters based on the three waste streams. The *Recycls* are monsters representing the recycling bins. Meanwhile, the *Trashers* and the *Composters* represent the landfill and composting bins (see Figure 5). Each of these monster bins has their values for health and attack point, speed, ammo damage, and attack style (see Table 2). Furthermore, each monster has an associated point system for throwing correct trash or incorrect trash. The design team also identified the most common trash present around the campus. They performed interviews in the cafeteria with the waste management team and collected observational data during lunch and dinner time at various points around campus. Based on the data, the design team selected four most common types of thrash for the three types of waste streams and monster (see Table w). In the game, each of the trash items must be thrown to the correct monster to transform it back to normal and gain points. The models for the monsters and the trash monsters were developed by using SketchUpTM, a free 3D modeling tool.

[Insert Figure 5]
[Insert Table 3]

4.2.2 User Interface and Interaction

The next step in the design was to set the aesthetics of the game, as they provide the look and feel of the environment [87]. To guide the aesthetics development, the team relied on previous research, in particular, Mayer’s cognitive theory of multimedia learning. Therefore, the aesthetics include the graphical user interface (GUI), which allows the user to interact with the game. To determine the aesthetics of the game the team went through a storyboarding process. Each part of the game mechanics was drawn to illustrate graphical elements to be included and

the user interaction features of the game. For example, in the start screen of the game, the design team developed a storyboard showing a start, help, and quit button, a paragraph describing the game, all set to a background of the campus with a trash monster (see Figure 6). For the main game phase, the team storyboarded the GUI of the heads-up display (HUD) that included the users' health, armor, and performance points. After the game was storyboarded, the design team developed a process map detailing how the user interaction would take place. Based on the storyboards the design team was able to easily transition to into the game development in the Unity™ game engine.

[Insert Figure 6]

4.3 Development

4.3.1 Game Development

Before the game development could take place, the design team had to select a game engine platform that would allow for the game to be published on multiple platforms, such as Windows and Mac computers. Additionally, the team had to select a game engine that would support the Oculus Rift head-mounted display system. Based on the team's research, the game engine that would satisfy these requirements would be Unity™. Unity™ is a game development environment with a powerful rendering engine. The engine is integrated with a complete set of intuitive tools and rapid workflows to create interactive 3D and 2D content [88]. The Unity™ game engine allowed the research team to incorporate photorealistic graphics, streamline the 3D content generation, and simplify the publication of the game. After selecting the game engine platform, the game development took place in two stages. First, the design team developed the virtual campus environment (see Figure 7). As mentioned earlier, the design team set the story of the game to be on the local university campus. To develop a virtual version of the campus, the team leveraged several software packages. First, the campus topography and roads were extracted by using Autodesk Infraworks™. This software allowed the designers to extract topography information in an FBX format. This file was then easily imported into Unity™. The after the topography was developed, the team started modeling the campus buildings with SketchUp™. Each of the building models was then exported in an FBX format and placed on the topographical model in Unity™. In the second stage of the development, the team translated the game mechanics and storyboard in the graphical user interface (GUI) of game. Unity™ allowed the team to easily develop GUI elements that would interact with the game elements (monsters and trash) through Java Scripts.

[Insert Figure 7]

4.3.2 Educational Material

Together with the game development, the design and research team developed educational material for classroom implementation. This material was designed to support instructors in their classroom implementation of the game and the assessment of the learning objectives. Therefore, to guide the implementation of the game, the team developed an Instructor's Guide and a User's Guide. The Instructor's Guide contains an implementation framework for instructors, which includes: a procedure map and activity duration, necessary technology, presentation to introduce recycling concepts, assessment material or instrument, and

evaluation rubric. The procedure map includes all of the steps, and their duration, that an instructor can take when implementing the game. In this process map, the team has included facilitation notes to guide instructors' implementation. One of these steps is to perform a short 20-minute presentation, included in the guide, to the students and introduce them to the importance of proper waste management. The assessment instrument was designed by aligning the questions to the game features and learning objectives (see Table 4). Therefore, the instrument can directly measure the students' learning gains before and after playing the game. In the Instructor's Guide, an instructor can find the correct answers to the questions, together with an evaluation rubric for the open-ended question. This rubric evaluates the quality of the students' answer on a 5-point scale, ranging from unsatisfactory to excellent, with examples for each level. The last implementation document that was developed by the team is the User Guide. This guide includes user directions for each scene in the game. This will be packaged in the installation files of the game for anyone to use.

[Insert Table 4]

5. Future Study and Research

Implementing *Attack of the Recyclops* and measuring its effects on sustainability learning and behavior with highest possible causal certainty is an integral part of this educational research project. Now that the game design and development, as well as the instructional and assessment tools are completed, the next phase is to conduct a series of true experiments where the learning implications of this game is compared to other traditional formats and platforms. Based on the implications of a set of educational and behavioral theories (chiefly, Bloom's taxonomy of educational objectives, Value-belief-norm theory [89], perceived consumer effectiveness [90], self-determination theory, construal level theory, mental resource depletion) as well as other related literature, propositions are developed where the learning platform (VR vs. computer desktop-based vs. textbook-based), educational content format (game vs. lecture) will be the three main independent variables while the learning outcomes, as well as pro-environmental attitudes and behaviors, will be the dependent variables [83], [84], [91], [92]. Hence, the initial experiment will have a 3 X 2 between-subjects design with one additional baseline condition (no educational content/platform), while subsequent experimental steps will incorporate moderating and mediating variables to help delineate the scope, boundary conditions and the process through which proposed effects of VR take place. Measures of learning outcomes will largely consist of the same items in the assessment tool. Pro-environmental attitudes, behavioral intentions (e.g., willingness to recycle) and choices (e.g., signing up for campus sustainability task force) will also be measured. Following the falsificationist paradigm, moderation and mediation of VR effects will be tested via a set of conceptually related variables, such as the type of motivation (intrinsic vs. extrinsic), depletion vs. vitalization of mental resources, temporal distance of assessment (immediate vs. delayed), psychological distance of the environmental concepts/issues. The main propositions that will be tested in a falsificationist experimental setting are presented below. Specific directional hypotheses before each experiment will be formulated based on these propositions.

P₁: Educational content related to sustainability will result in higher learning assessment results when it is delivered through the VR game (*Attack of the Recyclops*) compared to other platforms/formats and baseline condition.

P₂: Attitudinal and behavioral outcomes will be significantly different in the VR game (*Attack of the Recyclops*) condition compared to other conditions.

P₃: The psychological distance of environmental concepts/issues will mediate the effect of VR game on sustainability outcomes.

P₄: The depletion or vitalization of mental resources will mediate the effect of VR game on sustainability outcomes.

P₅: Temporal distance of assessment and motivation type will moderate all the sustainability outcomes, while personal values, beliefs, and perceived consumer effectiveness will moderate the attitudinal/behavioral outcomes.

Following the IRB approval, the experiments will mainly take place in the Immersive and Interactive Research Group Lab – a designated lab for VR learning and research at CSUEB. However, due to the portability of the VR equipment, stations might be set up in different controlled locations within the campus for different experiments. The participants will be CSUEB students and will be recruited via announcements in university websites, departmental listservs, webpages, and newsletters. Students will be randomly assigned to each experimental condition and the data collection period will be kept minimal for each experiment. Students will be debriefed on the purposes of the experiments after their participation. Additionally, demographic and educational background as well as familiarity/experience with Virtual Reality/computer based games will be collected as control variables. In addition to experiments, cross-sectional and longitudinal studies are planned to be conducted that investigate the relationships between the game and various learning and behavioral outcomes, academic performance, environmental activism/advocacy, etc. among campus students. By observing sustainability outcomes of the *Attack of the Recyclops* (as well as any curricular or extra-curricular activities that incorporate the game) in more natural educational settings, these correlational studies will allow the research team to observe the longer-term effects, identify more potential facilitators or inhibitors, and conduct additional experiments in the future.

6. Conclusions and Expected Outcomes

When waste is not properly disposed, it can contribute to global warming through the emission of greenhouse gasses, such as methane and carbon dioxide. Therefore, it is imperative to minimize the amount of waste that gets diverted to landfills. To combat this effect, California state legislature has put forward bills to regulate the flow of waste. This legislature requires that universities, as well as other entities, must contribute to the proper disposal of waste. To support this effort, college students need to be provided with environmental education that trains them and shapes their behavior to properly dispose of waste. One method to engage and instruct students and shape their behavior is through the use of educational video games. To further enhance the educational and behavioral impact of an educational video game, a researcher can leverage virtual reality. Virtual reality has illustrated its ability to stimulate strong emotional responses from users. Therefore, based on the provided background literature and research gap, the team has set the goal of evaluating the potential effect that a virtual reality educational game has on learning and behavior. It is the hope of the research team to provide evidence illustrating the role that an educational virtual reality game has in supporting environmental education and behavior.

Bibliography

- [1] A. S. Goudie, *The human impact on the natural environment: past, present, and future*. John Wiley & Sons, 2013.
- [2] B. S. Halpern *et al.*, “A global map of human impact on marine ecosystems,” *Science*, vol. 319, no. 5865, pp. 948–952, 2008.
- [3] J. P. Holdren and P. R. Ehrlich, “Human Population and the Global Environment: Population growth, rising per capita material consumption, and disruptive technologies have made civilization a global ecological force,” *American scientist*, vol. 62, no. 3, pp. 282–292, 1974.
- [4] P. M. Vitousek, H. A. Mooney, J. Lubchenco, and J. M. Melillo, “Human domination of Earth’s ecosystems,” *Science*, vol. 277, no. 5325, pp. 494–499, 1997.
- [5] M. Wackernagel and W. Rees, *Our ecological footprint: reducing human impact on the earth*. New Society Publishers, 1998.
- [6] “IPCC Fifth Assessment Report.” [Online]. Available: <https://www.ipcc.ch/report/ar5/>. [Accessed: 05-Dec-2017].
- [7] Environmental Protection Agency, “Advancing sustainable materials management: 2014 fact sheet,” Washington, DC, 2015.
- [8] P. Smith, D. Reay, and A. Van Amstel, *Methane and climate change*. Routledge, 2010.
- [9] “Bill Text - AB-1826 Solid waste: organic waste.” [Online]. Available: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1826. [Accessed: 20-Nov-2017].
- [10] R. Wuenschel, “Higher Education Needs Environmental Leadership,” 27-Feb-2001.
- [11] H. N. Apsan, “EPA’s college and university initiative: The city university of New York responds,” *Environmental Quality Management*, vol. 13, no. 2, pp. 21–29, 2003.
- [12] Environmental Protection Agency, “Colleges & Universities,” 2013.
- [13] Environmental Protection Agency, “Environmental Management Guide for Colleges and Universities,” 2007.
- [14] H. M. Alshuwaikhat and I. Abubakar, “An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices,” *Journal of Cleaner Production*, vol. 16, no. 16, pp. 1777–1785, 2008.
- [15] M. Dahle and E. Neumayer, “Overcoming barriers to campus greening: A survey among higher educational institutions in London, UK,” *International Journal of Sustainability in Higher Education*, vol. 2, no. 2, pp. 139–160, 2001.
- [16] P. B. Corcoran and A. E. Wals, *Higher education and the challenge of sustainability*. Springer, 2004.
- [17] M. P. Shriberg, “Sustainability in US higher education: organizational factors influencing campus environmental performance and leadership,” University of Michigan Ann Arbor, MI, 2002.
- [18] M. Shriberg, “Institutional assessment tools for sustainability in higher education: strengths, weaknesses, and implications for practice and theory,” *International Journal of Sustainability in Higher Education*, vol. 3, no. 3, pp. 254–270, 2002.
- [19] A. E. Wals and B. Jickling, “‘Sustainability’ in higher education: From doublethink and newspeak to critical thinking and meaningful learning,” *International Journal of Sustainability in Higher Education*, vol. 3, no. 3, pp. 221–232, 2002.

- [20] C. A. de Vega, S. O. Benítez, and M. E. R. Barreto, "Solid waste characterization and recycling potential for a university campus," *Waste management*, vol. 28, pp. S21–S26, 2008.
- [21] L. Velazquez, N. Munguia, and M. Sanchez, "Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions," *International Journal of Sustainability in Higher Education*, vol. 6, no. 4, pp. 383–391, 2005.
- [22] P. B. Corcoran, K. E. Walker*, and A. E. Wals, "Case studies, make-your-case studies, and case stories: a critique of case-study methodology in sustainability in higher education," *Environmental Education Research*, vol. 10, no. 1, pp. 7–21, 2004.
- [23] W. Lambrechts, I. Mulà, K. Ceulemans, I. Molderez, and V. Gaeremynck, "The integration of competences for sustainable development in higher education: an analysis of bachelor programs in management," *Journal of Cleaner Production*, vol. 48, pp. 65–73, 2013.
- [24] K. J. Whitehair, C. W. Shanklin, and L. A. Brannon, "Written messages improve edible food waste behaviors in a university dining facility," *Journal of the Academy of Nutrition and Dietetics*, vol. 113, no. 1, pp. 63–69, 2013.
- [25] R. J. Koester, J. Eflin, and J. Vann, "Greening of the campus: a whole-systems approach," *Journal of Cleaner Production*, vol. 14, no. 9, pp. 769–779, 2006.
- [26] R. Lukman, A. Tiwary, and A. Azapagic, "Towards greening a university campus: The case of the University of Maribor, Slovenia," *Resources, Conservation and Recycling*, vol. 53, no. 11, pp. 639–644, 2009.
- [27] J. Mcmillin and R. Dyball, "Developing a whole-of-university approach to educating for sustainability: linking curriculum, research and sustainable campus operations," *Journal of Education for Sustainable Development*, vol. 3, no. 1, pp. 55–64, 2009.
- [28] D. P. Smyth, A. L. Fredeen, and A. L. Booth, "Reducing solid waste in higher education: The first step towards 'greening' a university campus," *Resources, Conservation and Recycling*, vol. 54, no. 11, pp. 1007–1016, 2010.
- [29] K. Marcell, J. Agyeman, and A. Rappaport, "Cooling the campus: Experiences from a pilot study to reduce electricity use at Tufts University, USA, using social marketing methods," *International Journal of Sustainability in Higher Education*, vol. 5, no. 2, pp. 169–189, 2004.
- [30] B. L. Levy and R. W. Marans, "Towards a campus culture of environmental sustainability: recommendations for a large university," *International Journal of Sustainability in Higher Education*, vol. 13, no. 4, pp. 365–377, 2012.
- [31] J. Venetoulis, "Assessing the ecological impact of a university: the ecological footprint for the University of Redlands," *International Journal of Sustainability in Higher Education*, vol. 2, no. 2, pp. 180–197, 2001.
- [32] L. Pike, T. Shannon, K. Lawrimore, A. McGee, M. Taylor, and G. Lamoreaux, "Science education and sustainability initiatives: A campus recycling case study shows the importance of opportunity," *International Journal of Sustainability in Higher Education*, vol. 4, no. 3, pp. 218–229, 2003.
- [33] J. M. Hines, H. R. Hungerford, and A. N. Tomera, "Analysis and synthesis of research on responsible environmental behavior: A meta-analysis," *The Journal of environmental education*, vol. 18, no. 2, pp. 1–8, 1987.
- [34] R. B. Meyers, "Environmental learning: reflections on practice, research and theory," *Environmental Education Research*, vol. 12, no. 3–4, pp. 459–470, 2006.

- [35] M. Rickinson, "Learners and learning in environmental education: A critical review of the evidence," *Environmental Education Research*, vol. 7, no. 3, pp. 207–320, 2001.
- [36] M. Rickinson, C. Lundholm, and N. Hopwood, "What Is Environmental Learning?," in *Environmental Learning*, Springer, 2009, pp. 11–21.
- [37] J. L. Frand, "The Information-Age Mindset: Changes in Students and Implications for Higher Education," *EDUCASE Review* (2000), vol. 35, no. 5, 2000.
- [38] D. Jonas-Dwyer and R. Pospisil, "The Millennial effect: Implications for academic development," *Transforming Knowledge into Wisdom: Holistic Approaches to Teaching and Learning*, vol. HERDSA 2004 Conference Proceedings, pp. 195–207, 2004.
- [39] T. Nguyen, F. Mondragon, W. J. O'Brien, and K. Schmidt, "Understanding our students: a technology and construction baseline survey.," 2010.
- [40] D. Oblinger, "Boomers & Gen-Xers, Millennials: Understanding the 'New Students,'" *EDUCAUSE Review*, 2003.
- [41] M. Prensky, *Digital Game-Based Learning*. New York: McGraw-Hill, 2001.
- [42] "2016: the year when VR goes from virtual to reality - BBC News." [Online]. Available: <http://www.bbc.com/news/technology-35205783>. [Accessed: 06-Dec-2017].
- [43] A. Hern, "Will 2016 be the year virtual reality gaming takes off?," *The Guardian*, 28-Dec-2015.
- [44] "2016: The Year of Virtual Reality? | Fortune." [Online]. Available: <http://fortune.com/2015/12/04/2016-the-year-of-virtual-reality/>. [Accessed: 06-Dec-2017].
- [45] M. Cavazza, F. Charles, and S. J. Mead, "Developing re-usable interactive storytelling technologies," in *Building the Information Society*, Springer, 2004, pp. 39–44.
- [46] G. Riva *et al.*, "Affective interactions using virtual reality: the link between presence and emotions," *CyberPsychology & Behavior*, vol. 10, no. 1, pp. 45–56, 2007.
- [47] G. Thorsteinsson, "Developing an Understanding of the Pedagogy of Using a Virtual Reality Learning Environment (VRLE) to Support Innovation Education," *The Routledge International Handbook of Innovation Education. Edited by LV Shavinina. Oxford: Routledge. ISBN-10*, vol. 415682215, pp. 456–470, 2013.
- [48] R. E. Dunlap and W. R. Catton Jr, "Environmental sociology," *Annual Review of Sociology*, vol. 5, no. 1, pp. 243–273, 1979.
- [49] F. H. Buttel, "New directions in environmental sociology," *Annual review of sociology*, vol. 13, no. 1, pp. 465–488, 1987.
- [50] J. Hannigan, *Environmental sociology*. Routledge, 2014.
- [51] S. H. Schwarz, "Normative influences on altruism," *Advances in experimental psychology*, vol. 10, pp. 222–280, 1977.
- [52] P. C. Stern, T. Dietz, and G. A. Guagnano, "The new ecological paradigm in social-psychological context," *Environment and behavior*, vol. 27, no. 6, pp. 723–743, 1995.
- [53] A. Kollmuss and J. Agyeman, "Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?," *Environmental education research*, vol. 8, no. 3, pp. 239–260, 2002.
- [54] P. C. Stern, "New environmental theories: toward a coherent theory of environmentally significant behavior," *Journal of social issues*, vol. 56, no. 3, pp. 407–424, 2000.
- [55] N. J. Goldstein, R. B. Cialdini, and V. Griskevicius, "A room with a viewpoint: Using social norms to motivate environmental conservation in hotels," *Journal of consumer Research*, vol. 35, no. 3, pp. 472–482, 2008.

- [56] P. W. Schultz and L. Zelezny, "Values as predictors of environmental attitudes: Evidence for consistency across 14 countries," *Journal of environmental psychology*, vol. 19, no. 3, pp. 255–265, 1999.
- [57] C. Thøgersen-Ntoumani and N. Ntoumanis, "The role of self-determined motivation in the understanding of exercise-related behaviours, cognitions and physical self-evaluations," *Journal of sports sciences*, vol. 24, no. 4, pp. 393–404, 2006.
- [58] H. R. Hungerford and T. L. Volk, "Changing learner behavior through environmental education," *The journal of environmental education*, vol. 21, no. 3, pp. 8–21, 1990.
- [59] J. Palmer, *Environmental education in the 21st century: Theory, practice, progress and promise*. Routledge, 2002.
- [60] D. Tilbury, "Environmental education for sustainability: Defining the new focus of environmental education in the 1990s," *Environmental education research*, vol. 1, no. 2, pp. 195–212, 1995.
- [61] R. R. Ballantyne and J. M. Packer, "Teaching and learning in environmental education: Developing environmental conceptions," *The Journal of Environmental Education*, vol. 27, no. 2, pp. 25–32, 1996.
- [62] I. G. Mason, A. K. Brooking, A. Oberender, J. M. Harford, and P. G. Horsley, "Implementation of a zero waste program at a university campus," *Resources, Conservation and Recycling*, vol. 38, no. 4, pp. 257–269, 2003.
- [63] D. H. Schunk, *Learning Theories: An Educational Perspective*, 6 edition. Boston: Pearson, 2011.
- [64] L. P. Rieber, "Multimedia learning in games, simulations, and microworlds," *The Cambridge handbook of multimedia learning*, pp. 549–567, 2005.
- [65] R. E. Mayer, *The Cambridge Handbook of Multimedia Learning*. Cambridge University Press, 2005.
- [66] C. Aldrich, *Simulations and the Future of Learning: An Innovative (and Perhaps Revolutionary) Approach to e-Learning*. Jossey-Bass Inc., Publishers, 2003.
- [67] K. Squire, "Changing the game: What happens when video games enter the classroom?," *Innovate 1* (6), 2005.
- [68] J. P. Gee, "What video games have to teach us about learning and literacy," New York : Palgrave Macmillan, 2007, 2007.
- [69] K. Katsaliaki and N. Mustafee, "A survey of serious games on sustainable development," in *Simulation Conference (WSC), Proceedings of the 2012 Winter*, 2012, pp. 1–13.
- [70] S. Blackman, "Serious games... and less!," *ACM Siggraph Computer Graphics*, vol. 39, no. 1, pp. 12–16, 2005.
- [71] D. R. Michael and S. Chen, *Serious Games: Games That Educate, Train, And Inform*. Thomson Course Technology, 2006.
- [72] F. Castronovo, P. N. Van Meter, S. E. Zappe, R. M. Leicht, and J. I. Messner, "Developing Problem-Solving Skills in Construction Education with the Virtual Construction Simulator," *INTERNATIONAL JOURNAL OF ENGINEERING EDUCATION*, vol. 33, no. 2, pp. 831–846, 2017.
- [73] Y. Hirose, J. Sugiura, and K. Shimomoto, "Industrial waste management simulation game and its educational effect," *Journal of Material Cycles and Waste Management*, vol. 6, no. 1, pp. 58–63, 2004.

- [74] T. A. Philpot, R. H. Hall, N. Hubing, and R. E. Flori, "Using games to teach statics calculation procedures: Application and assessment," *Computer Applications in Engineering Education*, vol. 13, no. 3, pp. 222–232, 2005.
- [75] F. Castronovo, "Assessing Problem-Solving Skills in Construction Education with the Virtual Construction Simulator," 2016.
- [76] F. Castronovo, S. E. Zappe, R. M. Leicht, and J. I. Messner, "Design of a Construction Simulation Educational Game Through a Cognitive Lens," presented at the 2015 ASEE Annual Conference and Exposition, Seattle, Washington, 20-Jun-2015.
- [77] C. Fabricatore and X. Lopez, "Sustainability Learning through Gaming: An Exploratory Study," *Electronic Journal of e-Learning*, vol. Volume 10, no. Issue 2, pp. 209–222, 2012.
- [78] D. A. Bowman and R. P. McMahan, "Virtual Reality: How Much Immersion is Enough?," *Computer*, vol. 40, no. 7, pp. 36–42, 2007.
- [79] J.-W. Lin, H. B.-L. Duh, D. E. Parker, H. Abi-Rached, and T. A. Furness, "Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment," in *Virtual Reality, 2002. Proceedings. IEEE*, 2002, pp. 164–171.
- [80] G. R. Morrison, *Designing effective instruction*. Hoboken, NJ: Wiley, 2011.
- [81] R. K. Branson, G. T. Rayner, J. L. Cox, J. P. Furman, F. J. King, and F. S. U. T. C. F. E. TECHNOLOGY, *Interservice Procedures for Instructional Systems Development*. Defense Technical Information Center, 1975.
- [82] H. M. Cannon and A. C. Burns, "A Framework For Assessing The Competencies Reflected In Simulation Performance," *Developments in Business Simulation & Experiential Exercises*, vol. 26, pp. 40–44, 1999.
- [83] B. S. Bloom, *Taxonomy of educational objectives: The classification of educational goals*. United Kingdom: Longman Group United Kingdom, 1969.
- [84] L. W. Anderson and D. R. Krathwohl, *A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives*. New York: Longman, 2001.
- [85] F. Castronovo, R. M. Leicht, J. I. Messner, S. E. Zappe, and D. Nikolic, "Enhancement of Learning Objectives in Construction Engineering Education: A Step toward Simulation Assessment," in *Construction Research Congress 2014*, 2014, pp. 339–348.
- [86] R. Heer, "A Model of Learning Objectives–based on A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives," Center for Excellence in Learning and Teaching, Iowa State University, Mar-2009.
- [87] J. Schell, *The art of game design a book of lenses. - Description based on print version record*. Boston: Elsevier/Morgan Kaufmann, 2008.
- [88] Unity Technologies, "The future of visualization in architecture." .
- [89] P. C. Stern, T. Dietz, T. Abel, G. A. Guagnano, and L. Kalof, "A value-belief-norm theory of support for social movements: The case of environmentalism," *Human ecology review*, pp. 81–97, 1999.
- [90] T. C. Kinnear, J. R. Taylor, and S. A. Ahmed, "Ecologically concerned consumers: who are they?," *The Journal of Marketing*, pp. 20–24, 1974.
- [91] R. M. Ryan and E. L. Deci, "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being," *American Psychologist*, vol. 55, no. 1, pp. 68–78, 2000.
- [92] Y. Trope and N. Liberman, "Construal-level theory of psychological distance.," *Psychological review*, vol. 117, no. 2, p. 440, 2010.

APPENDICES

Figure 1. ADDIE Design Process for the *Attack of the Recyclops* Game

Figure 2. CSUEB Students in the Visualization and Immersion Classroom

Lower order thinking skills			Higher order thinking skills		
Remember	Understand	Apply	Analyze	Evaluate	Create
Recognizing Identifying Recalling	Interpreting Clarifying Exemplifying Illustrating Classifying Summarizing Inferring Comparing Explaining	Executing Implementing	Differentiating Selecting Organizing Attributing	Checking Testing Judging Critiquing	Hypothesizing Planning Producing

Figure 3. Categories of learning skills and cognitive processes (adapted from Heer) [86]

Figure 4. Game Mechanics

Figure 5. Trash Bin Monsters

Figure 6. Start Screen and Main Screen Storyboard

Figure 7. Virtual Campus in Unity 3D

Table 1. Learning Objectives of the Attack of the Recyclops

Cognitive Domain	Action Verb	Learning Objective
At the end of the pedagogical intervention the students will be able to:		
Remembering	Identify Match	1. Identify the different types of trash bins. 2. Match the symbol/label to the correct colored trash bins.
Understanding	Explain Summarize	3. Explain/Summarize the importance of properly choosing the correct waste stream.
Applying	Choose	4. Choose the correct waste stream for the presented trash.

Table 2. Structure of the Attack of the Recyclops

Game Scene	Game Mechanics	Purpose of the Scene
Start Screen	Start Game	Introduce the game and learning objectives.
Introduction Scene	Introduction Narrative	Have voice-over introduction to the story of the game.
Tutorial Scene	Start Tutorial	Introduce the navigation and shoot mechanics of the game.
Load Scene	Load Campus	Load main game scene.
Main Game Scene	Pick Up Slingshot Pick Up Trash Feed Correct Trash to Bins Transform All Bins	Main scene where the user has to collect trash and throw it at the correct monsters to transform them back into regular bins.
End Screen	End Game	Provide to the user an end screen illustrating: the total number of monsters transformed; correct trash thrown; and total points collected.

Table 3. Monster Statistics and Trash Types

Stats	Recycls	Monsters	
		Trashers	Composters
Health Points	120	200	150
Attack	5	15	10
Speed	30	20	40
Ammo Damage	40	40	50
Attack Style	Basic Brute	Heavy Brute	Quick Brute
Points for Correct Trash	400	200	600
Points Incorrect Trash	-800	-800	-800
Acceptable Trash	Plastics 1-7 Paper Glass Cans	Sandwich Bags Bubble-wrap Chip Bags Wax Paper Cups	Banana Tomato Apple Pizza

Table 4. Assessment Instrument

Learning Objective	Question Type	Question
--------------------	---------------	----------

1. Identify the different types of trash bins.	Multiple Choice	1. What type of bin is this? (Recycling) 2. What type of bin is this? (Composting) 3. What type of bin is this? (Landfill)
2. Match the symbol/label to the correct colored trash bins.	Multiple Choice	4. What color is the composting bin? 5. What symbol is on the recycling bin? 6. What symbol is on the landfill bin?
3. Explain the importance of properly choosing the correct waste stream.	Open-ended	7. Why is it important to throw trash in the correct bin?
4. Choose the correct waste stream for the presented trash.	Multiple Choice	8. In which bin would you throw this item? (Banana peel) 9. In which bin would you throw this item? (Plastic bottle) 10. In which bin would you throw this item? (Wax paper cup)