KNOWLEDGE DISCOVERY OF GAMIFICATION FEATURES RELEVANT TO IMMERSIVE VIRTUAL REALITY ENVIRONMENTS

A Thesis in
Industrial Engineering

by

Ajay Karthie B. Gopinath Bharathi

© 2015 Ajay Karthie B. Gopinath Bharathi

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

May 2015
The thesis of Ajay Karthic B. Gopinath Bharathi was reviewed and approved* by the following:

Conrad S. Tucker
Assistant Professor of Industrial and Manufacturing Engineering
Thesis Advisor

John I. Messner
Charles and Elinor Matts Professor of Architectural Engineering

Harriet B. Nembhard
Professor of Industrial and Manufacturing Engineering
Interim Head of the Department of Industrial and Manufacturing Engineering

*Signatures are on file in the Graduate School
ABSTRACT

Virtual Reality (VR) is a three dimensional interactive world that gives users the impression of being somewhere other than where they actually are. Over the last decade, a wide range of VR applications have been developed, based on VR environments. Immersive VR environment is a type of VR environment that produces an interactive computer generated world of high ecological validity, in which the users can “immerse” themselves using a variety of 3D stimuli. On the other hand, non-immersive VR environment is the least immersive implementation of VR techniques in which the virtual environment is viewed through a portal or window by utilizing a standard high resolution monitor and interactions occur using 2D interaction devices such as keyboards and mice. A major limitation of non-immersive VR environments is the lack of immersive experience that not only provides content to users, but also enables them to interact in a completely 360 degree immersive environment. Furthermore, a knowledge gap exists in terms of what motivates individuals to utilize such systems. This thesis aims to fill these research gaps by first i) exploring whether there exists statistically significant differences in performance between users in immersive VR and non-immersive VR environments and then ii) proposing the use of video game design elements in non-game contexts (i.e., immersive VR environments) to motivate and increase user engagement, otherwise known as “gamification”. A case study involving 54 individuals carrying out a product functional analysis task is used to test the hypothesis that immersive VR environments, such as those achievable through head-mounted displays, enhance performance outcomes when compared to non-immersive VR environments. A case study involving 60 games from the Android market is used to understand the fundamental aspects of video games that make them engaging and motivating. Seven game design elements
(challenges, levels, win states, social graph, rewards, content unlocking and leaderboards) are found to motivate users and maintain user engagement for extended periods of time and could be potentially integrated into immersive VR environments to make them more engaging and motivating for users.
# TABLE OF CONTENTS

List of Figures ........................................................................................................................................... vii

List of Tables ............................................................................................................................................... viii

Acknowledgements ....................................................................................................................................... ix

Chapter 1 Introduction .............................................................................................................................. 1

Chapter 2 Literature Review ...................................................................................................................... 6

  2.1 Virtual Reality Systems ..................................................................................................................... 6
    2.1.1 Immersive vs. Non-Immersive Virtual Reality Systems ............................................................. 7
    2.1.2 Applications of Virtual Reality in Education ............................................................................ 8

  2.2 Motivation Through Gamification .................................................................................................... 12
    2.2.1 Applications of Gamification .................................................................................................... 13
    2.2.2 Game Design Elements ............................................................................................................ 15

Chapter 3 Methodology ............................................................................................................................ 19

  3.1 Investigating the Difference between Immersive and Non-Immersive VR System .................... 19
  3.2 Identification of Successful Game Design Elements ...................................................................... 23

Chapter 4 Case Studies and Discussion ................................................................................................ 27

  4.1 Case Study 1: Product Functional Analysis ...................................................................................... 28
    4.1.1 Research Environment ............................................................................................................. 29
    4.1.2 Virtual Reality Setup – Hardware, Software and Environment ............................................. 29
    4.1.3 Experimental Study .................................................................................................................... 32
    4.1.4 Study Results .............................................................................................................................. 34
4.2 Case Study 2: Mining Features of Android Games.........................................................39
4.2.1 Step 1 – Selection of Game Design Elements .............................................................39
4.2.2 Step 2 – Selection of Platform and Sample Games ......................................................40
4.2.3 Step 3 – Data Collection..............................................................................................41
4.2.4 Step 4 – Confusion Matrix - Game Design Element vs. Success of Game .........42
4.2.5 Step 5 – Confusion Matrix - Game Design Element vs. Game Sentiment ......43
4.2.6 Step 6 – Comparison of Results ..................................................................................46

Chapter 5 Conclusions and Future Work...............................................................................48

Appendix Product Functional Analysis - Experiment Questionnaire ..................................52

References..................................................................................................................................56
LIST OF FIGURES

Figure 3-1: Outline of Overall Methodology ........................................................................... 19

Figure 3-2: Methodology to Evaluate Immersive vs. Non-Immersive VR Systems .......... 20

Figure 3-3: Six Degrees of Freedom Achieved Using Immersive VR Systems ............... 21

Figure 3-4: Methodology to Identify Successful Game Design Elements ....................... 23

Figure 4-1: Overall Methodology with Case Studies .......................................................... 27

Figure 4-2: Laboratory Setup of Immersive VR System (Oculus Rift®) ......................... 29

Figure 4-3: VR Environment of the Product Functional Analysis Task ........................... 31

Figure 4-4: Left and Right Eye Images of the VR Environment in Oculus Rift® .............. 31

Figure 4-5: Student Using Immersive VR System (Oculus Rift®) ................................... 33

Figure 4-6: Student Using Non-Immersive VR System ..................................................... 34

Figure 4-7: Box Plot Comparing Task Completion Time of Two Groups ....................... 35

Figure 4-8: Students Response to Statement 1 in Post-Experiment Questionnaire ....... 36

Figure 4-9: Students Response to Statement 2 in Post-Experiment Questionnaire ........ 37

Figure 4-10: Group 1 (Immersive VR System) Students Response to Statement 3 and 4 .... 38

Figure 4-11: Games Sampling from Android Market ......................................................... 41

Figure 4-12: Comparison of Results ................................................................................... 47
LIST OF TABLES

Table 2-1: Types of VR Systems outlined by Mujber et al. [28] ........................................... 7

Table 2-2: Literature on Game Mechanics ................................................................. 16

Table 2-3: Literature on Game Components .............................................................. 17

Table 3-1: Representation of \( n \times m \) Matrix (Step 3) .............................................. 24

Table 3-2: Confusion Matrix – Game Design Element vs. Success of Game (Step 4) ....... 25

Table 4-1: Median Task Completion Time of Two Groups ............................................ 35

Table 4-2: Sample Data Collected .................................................................................. 41

Table 4-3: Confusion Matrix – Presence of 'Challenge' vs. Success of Game ............... 42

Table 4-4: Summary of Precision, Recall and F-score at Step 4 ........................................ 43

Table 4-5: Sample Data Collected - Sentiment Scores ...................................................... 44

Table 4-6: Confusion Matrix – Presence of 'Challenge' vs. Game Sentiment ............... 45

Table 4-7: Summary of Precision, Recall and F-score at Step 5 ........................................ 46
ACKNOWLEDGEMENTS

Firstly, I would like to express my heartfelt gratitude and thanks to my advisor, Dr. Conrad Tucker for his guidance and support during the course of this thesis. Dr. Tucker’s constant encouragement and patience has been invaluable during this period. I would like to thank him for his advice and encouragement throughout my graduate study at Penn State University. I would also like to thank my thesis reader – Dr. John Messer for taking time to review my thesis and giving suggestions for improvement.

I would like to acknowledge the Penn State’s Center for Online Innovation in Learning (COIL) and Center for Health Organization Transformation (CHOT) for the grant that funded this research. I would like to thank the members of Design Analysis Technology Advancement (D.A.T.A.) lab for their support, especially Bryan Dickens, Steven Sellers, Gabe Harms and Owen Shartle for their time and hard work in developing the virtual reality environment for this research and also Matt Dering, Tian Zhou for developing the web crawler tool.

Last but not least, I would like to thank my parents Gopinath Bharathi and Shanthi Gopinath, and my sister Abhinaya Bharathi for always believing in me, making me the person I am today, and for supporting me at every step of my life.
Chapter 1

Introduction

VR is a computer generated virtual environment that gives users the impression of being somewhere other than where they actually are. VR can be considered as an advanced form of human-computer interface that allows the user to interact with a realistic virtual environment generated using interactive software and hardware. A more formal definition of VR was proposed by Moshell and Hughes [1], where they define VR “as a real-time graphical simulation with which the user interacts via some form of analog control, within a spatial frame of reference and with user control of the viewpoint’s motion and view direction”. VR technology has been widely proposed as a powerful and promising tool that can offer significant support for a wide range of domains. Advancements in computer hardware technology and internet connectivity have made VR increasingly popular and less expensive. According to a recent report [2], the VR market is expected to grow to $407.51 million and reach more than 25 million users by 2018. This increased demand is attributed to a broad spectrum of application areas for these technologies outside of the gaming world. Today, VR technologies are used in fields such as education, military, healthcare, entertainment, engineering, sports, and much more [3]–[8]. Previous research found that information is absorbed best when using more than one human sense; that is, 10 % of the information is taken in by reading, 30 % by reading and visuals, 50 % by reading, visuals and sound and 80 % by reading, visuals, sound and interaction [9]. Therefore, video, audio and interaction are the three most powerful forms of communicating information in learning environments and VR technology allows great potential for providing such learning environments.
The primary characteristics of VR that differentiate it from other means of displaying information are the concepts of immersion and presence. The VR research community is divided on its opinion about the differences between immersion and presence. Slater and Wilbur [10] define immersion based on the description of what any technology could provide i.e. the extent to which the computerized system is capable of offering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a user. According to them, “Inclusive indicates the extent to which physical reality is shut out. Extensive indicates the range of sensory modalities accommodated. Surrounding indicates the extent to which this virtual reality is panoramic rather than limited to a narrow field. Vivid indicates the resolution, fidelity, and variety of energy simulated within a particular modality”. They define presence “as a state of consciousness, the (psychological) sense of being in the virtual environment”. It can be argued that a virtual environment that produces a greater sense of immersion will produce higher levels of presence [11]. At times, immersive VR environments are confused with the traditional 3D desktop environments. Van Dam et al. indicate that immersive VR environments are substantially new mediums that are different from the 3D desktop environments since “conventional desktop 3D displays give one the sensation of looking through a window into a miniature world on the other side of the screen, with all the separation that sensation implies, whereas immersive VR makes it possible to become immersed in and interact with life-sized scenes” [12]. Therefore, immersive VR environments let users “see” things which they could not see with the desktop graphics.

Immersive VR technology provides a suitable platform for the learner to participate in the learning environment with a sense of being a part of it [13]. Pantelidis provides several reasons for the use of VR in education, such as enhanced visualization, motivation, interaction and
collaboration [14]. Mikropoulos and Natsis reviewed 53 empirical studies related to the educational application of VR and found that several studies showcased the positive attitude of students and teachers towards the use of VR in educational settings [15]. They also pointed out that many studies demonstrated the potential of virtual environments as a tool to enhance students’ understanding of concepts and minimize misconceptions. VR systems have been shown to be an effective and promising tool for learning by enabling learners to visit virtual environments and interact with objects and space in real time, thereby overcoming traditional distance, time, or safety constraints [16], [17].

Though the VR environments have the ability to provide users with an extremely rich atmosphere for learning, the success of the VR environment does not depend exclusively on the type of immersive VR environment. One of the challenges in designing VR environments is that of motivating and engaging users since not all users share the same level of motivation and engagement. In order to engage users who are characterized by low interest or lack of motivation due to switch from one type of medium (for example, traditional brick and mortar classroom) to another (for example, virtual classroom), there is a need to have a fundamental understanding of what motivates individuals to participate in the VR environment. Therefore, this thesis investigates ways to design immersive VR environments in such a way that they are inherently motivating and engaging.

Video games are one of the most successful applications of virtual environments in recent times. They offer several effective ways to motivate users into action. The video game industry has been around for 40 years and has advanced the fundamental understanding of what motivates and engages people. According to Self Determination Theory (SDT) [18], “Three innate
psychological needs – competence, autonomy, and relatedness – which when satisfied yield enhanced self-motivation and mental health and when thwarted lead to diminished motivation and well-being”. A brief review suggests that video games have developed the ability to provide the basic psychological needs specified by SDT. Over time, video game developers have learned to harness the magnetic engagement and motivational appeal of video games by using various game design elements. Fogg's Behavior Model (FBM) [19] studies the factors that can generate a certain behavior and it is highly applicable to the case of human-computer interaction. “The FBM asserts that for a person to perform a target behavior, he or she must (i) be sufficiently motivated, (ii) have the ability to perform the behavior, and (iii) be triggered to perform the behavior. These three factors must occur at the same moment, for the behavior to happen”. This temporal convergence of motivation, ability and trigger is why game design elements are able to modify, alter and manipulate human behaviors. Video games have been known for engaging users for hours in pursuit of a goal. A survey by Entertainment Software Association has reported that more than 200 million hours are spent each day playing computer and video games by people in the U.S [20]. By age 21, the average American has spent more than 10,000 hours playing such games which is equivalent to five years of working a full-time job 40 hours per week [21], [22]. The above discussed research provides evidence that video games have the ability to motivate users into action and also engage them for extended periods of time.

The concept of using video game design elements in non-game contexts to motivate and increase user engagement is termed as “gamification” [23] and has rapidly gained traction in interaction design and digital initiatives of various organizations. According to Zichermann, the phenomenon of gamification can be explained as “if you can make something more fun, and
include notions of play, you can get people to do things they otherwise might not want to do” [24]. Gamification has attracted the interest of marketers, educationists, healthcare providers and others interested in driving for extended periods of user engagement. In the field of education, it has been reported that virtual environments like computer games can motivate individuals to engage in learning activities and has achieved promising results [25], [26]. Research has showed that the “game” nature of virtual environments has a positive impact on individuals’ motivation and engagement in the learning activities [27]. Given the potential of the VR environments, it is imperative that the VR developers have a thorough understanding of the users and prior knowledge about the game design elements which can successfully motivate and achieve user engagement for extended periods of time. Therefore, the game design elements that can achieve such high levels of motivation and engagement in virtual environments are explored. The successful game design elements that are identified, could be embedded into interactive immersive VR environments to motivate users to accomplish various goals in a variety of fields.

To summarize, the two objectives of this research are: 1) To test the hypothesis that immersive VR environments, such as those achievable through the head-mounted displays, enhance performance outcomes when compared to non-immersive VR environments; and 2) To identify the game design elements in the virtual environments, such as those generated by the immersive VR system, that enhance motivation and engagement. The thesis is organized as follows: Chapter 2 reviews related research; Chapter 3 outlines the research hypothesis and methodology; Chapter 4 describes the case studies and analyzes the results; and Chapter 5 discusses the conclusions and future directions.
Chapter 2

Literature Review

This chapter is divided into two sections. The first section reviews literature related to types of VR systems and successful implementations of VR systems in education. The second section reviews literature related to applications of gamification and successful implementation of various game design elements in virtual environments to motivate and engage users.

2.1 Virtual Reality Systems

VR environments can be generated by integrating a collection of hardware such as a computer, keyboard, mouse, head-mounted display, headphone or motion sensing gloves, with necessary software systems. Mujber et al. classify VR systems based on immersion into three categories namely: non-immersive (desktop) systems, semi-immersive projection systems and fully immersive systems as shown in Table 2-1 [28]. Fully immersive VR systems allow for mobility by capturing human motion and interaction with objects, and reproducing the same in the virtual 3D environments [29]. Non-immersive/desktop VR systems place the users in a virtual 3D environment and allow interaction utilizing a conventional graphic workstation with a monitor, keyboard and mouse [30]. Semi-immersive VR is another type of VR system that exists at the intersection between non-immersive and fully immersive VR systems. Fish tank VR on a monitor [31], workbenches [32] and single wall project displays [33], all with head-tracked stereo are examples of semi immersive VR systems. In this thesis, the term ‘immersive VR system’ is used synonymous to ‘fully immersive VR system’.
Table 2-1: Types of VR Systems outlined by Mujber et al. [28]

<table>
<thead>
<tr>
<th>VR system</th>
<th>Non-immersive VR</th>
<th>Semi-immersive VR</th>
<th>Fully-immersive VR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input devices</strong></td>
<td>Mice, keyboards, joysticks, and trackballs</td>
<td>Joystick, space balls and data gloves</td>
<td>Gloves and voice commands</td>
</tr>
<tr>
<td><strong>Output devices</strong></td>
<td>Standard high-resolution monitor</td>
<td>Large screen monitor, large screen projector system, and multiple television projection systems</td>
<td>Head mounted display (HMD), CAVE™</td>
</tr>
<tr>
<td>Resolution</td>
<td>High</td>
<td>High</td>
<td>Low–medium</td>
</tr>
<tr>
<td>Sense of immersion</td>
<td>Non–low</td>
<td>Medium–high</td>
<td>High</td>
</tr>
<tr>
<td>Interaction</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Price</td>
<td>Lowest cost VR system</td>
<td>Expensive</td>
<td>Very expensive</td>
</tr>
</tbody>
</table>

2.1.1 Immersive vs. Non-Immersive Virtual Reality Systems

Non-immersive/desktop VR systems have been found to be implemented in a plethora of applications like industrial training [34], preflight navigation training [35], rehabilitation of functional activities in patients with chronic stroke [36], visualizing geographical data [37] and astronomy education [38]. As explained earlier, the fully immersive VR systems require a more sophisticated setup to “immerse” the user in the computer generated 3D world. Head-mounted display based systems are one of the oldest types of fully immersive VR systems where the virtual environment is displayed via head-mounted visual display unit and user interaction with the virtual
environment takes place through a hand-held input device. Another type of fully immersive VR system is the Immersive Project Technology (IPT), where the images are projected on single or multiple screens around the user. CAVE™ is an example of such a system, where the user wearing stereoscopic LCD shutter glasses is placed in a cubical room and the virtual environment is projected on multiple surfaces, thereby giving the user a 3D feel of the virtual world. In the auto industry, BMW used the CAVE™ system to modify the design of cars by assembling and disassembling parts in the virtual world [7]. CAVE™ systems have been found to be used in the treatment of acrophobia [39], understanding molecular structure in chemistry education [40] and training nuclear power plant workers [41]. These types of fully immersive VR technologies have the ability to provide an interactive and stimulating platform for students and create a learning experience similar to the one which they might experience in an actual university.

2.1.2 Applications of Virtual Reality in Education

VR can be pedagogically exploited through its special characteristics such as three dimensional spatial representations, multisensory channels for user interaction, immersion and intuitive interaction through natural manipulations in real time [42]. There is general consensus among educational technologists about the need for interactivity in learning [43]. VR technology allows great potential for providing such immersive and interactive learning environments for individuals. Constructionism is one of the most widely accepted theories of learning and education of the 21st century. It is generally recognized in educational circles that an essential part of the learning process lies in “hands-on” construction. The constructivism learning theory argues that people produce knowledge and form meaning based upon their experiences [44]. The
constructivism learning theory suggests that the construction of an individual’s new knowledge is based on two concepts namely, assimilation and accommodation. Assimilation describes how the learners deal with new knowledge, while accommodation describes how learners reorganize their existing knowledge [45]. Discovery learning is a constructive based approach to education which is defined as “an approach to instruction through which students interact with their environment – by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments” [46]. Researchers have established the compatibility between characteristics of VR technology and constructivist learning theory [47]–[49]. The support that VR technology provides for constructivist learning is discussed in detail by Winn [49]. Winn suggests that VR technology allows three kinds of knowledge building experiences that are important for learning but are not available in the real world. These pertain to size, transduction, and reification. He also concluded that “(1) Immersive VR furnishes first-person non-symbolic experiences that are specifically designed to help students learn material. (2) These experiences cannot be obtained in any other way in formal education. (3) This kind of experience makes up the bulk of our daily interaction with the world, though schools tend to promote third-person symbolic experiences. (4) Constructivism provides the best theory on which to develop educational applications of VR. (5) The convergence of theories of knowledge construction with VR technology permits learning to be boosted by the manipulation of the relative size of objects in virtual worlds, by the transduction of otherwise imperceptible sources of information, and by the reification of abstract ideas that have so far defied representation”.

Studies have been conducted to investigate the preferences of students towards hands-on/tactile and digital/virtual learning environments [50], [51]. In physical brick and mortar
learning environments, the dissemination of information is typically constrained by distortion of line of sight, distortion of sound waves and inability to interact with objects. VR technology is a potential tool to overcome these limitations of a physical brick and mortar learning environment, by minimizing the variability in video/audio quality and providing an opportunity for individuals to interact with virtual objects. Previous research has shown that three-dimensional virtual worlds provide a better representation of the real world and are more effective than text-based or two-dimensional environments, and the increased degree of realism can lead to better student engagement in learning activities [52]. Researchers have investigated the use of VR for educating students of different ages in various fields and found positive performance and learning outcomes. Few applications of immersive and non-immersive VR systems in education are discussed below.

In the field of biology, Allison et al. created ‘Virtual Reality Gorilla Exhibit’, an immersive VR educational tool for middle school students wherein the users assumed a character of an adolescent gorilla to explore a virtual gorilla habitat, to learn about the gorillas’ interactions, vocalizations and social structures [53]. In chemistry, Limniou et al. showed that CAVE™ systems enabled students to get a clearer understanding of molecular structures and their changes during a chemical reaction when compared to 2D animation on desktop computers [40].

Non-Immersive VR systems have been widely used in various fields of education. In mathematics, VR has shown positive effects on students learning geometry topics [54], [55]. Kim et al. used an education tool called Virtual Reality Physics Simulation (VRPS) for visualization of key physics concepts such as wave propagation, ray optics, relative velocity and electric machines at high school or college level [56]. The survey results of the study indicated that students were more satisfied and felt that VR helped them understand the concepts better. Another example for
the application of VR in physics was demonstrated by Demaree et al. where three VR-based labs dealing with linear motion, circular motion and collision were created for the introductory physics laboratories [57]. VR systems are being used extensively in the field of astronomy education since it is not possible for students to visit space to learn astronomical phenomena. One such VR astronomy system is the ‘Virtual Solar System’ [58] where undergraduate students build a solar system using 3D modelling software. During the process, students are found to gain rich understanding of the astronomical phenomena. The Harvard Law School has offered virtual courses in Second Life, in which a specific set of students could participate in the lectures and interact with the instructor inside the virtual environment and the overall response was found to be positive [59]. One of the most important application of VR is in the education and training of medical professionals. VR allows medical professionals to recreate the operating room for ongoing training purposes. Ahlberg et al. demonstrated that VR training significantly reduced the error rate of residents during their first 10 laparoscopic cholecystectomies [60]. Another similar study concluded that VR surgical simulation improved the operating room performance of residents during laparoscopic cholecystectomy [61].

Though there has been a modest amount of research conducted using non-immersive VR systems in the educational setting, the exploration of immersive VR system seems to be lacking literature. Mikropoulos and Natsis [15] performed a ten year (1999-2009) review of empirical studies related to educational virtual environments and found that only 16 of the 53 studies used either immersive or semi immersive VR systems. There is a need to explore the effectiveness of VR technology in the educational setting and measure the users’ performance while being engaged in the VR environment [62]. Many studies have explored the use of VR systems for learning
activities, but to the best knowledge of the author, this is the first study that has been carried out in the direction of evaluating users’ performance in immersive VR systems versus non-immersive VR systems for online engineering design activities.

2.2 Motivation Through Gamification

Though VR technologies provide useful tools to help overcome the limitations of two-dimensional learning materials, the level of motivation exhibited by individuals to engage in the VR environments may vary. According to Curry and Adams, the motivation level of learners significantly depends on the learning environment [63]. Previous studies have shown that there is a strong relation between the level of motivation exhibited by individuals and their respective achievements in the virtual learning environment [64], [65]. Lack of motivation from the individuals to use new technology and learn independently are seen as major drawbacks of virtual learning environments [66]. Gamification can be seen as an innovative approach to foster motivation in a wide range of domains. According to Zichermann, gamification is 75% psychology and 25% technology [67]. Huczynski and Buchanan defined motivation as the “internal psychological process of initiating, energizing, directing and maintaining goal-directed behavior” [68]. Sailer et al. showed how different game design elements address different motivational mechanisms derived from six psychological perspectives (trait, behaviorist learning, cognitive, self-determination, interest, emotion) and thereby foster motivation [69]. This motivational pull by game elements can be utilized to influence the behavior of the users in the virtual environment towards achieving the goal. Therefore, gamification offers an effective platform to generate positive effects in individuals’ motivation and engagement.
2.2.1 Applications of Gamification

In education, gamification has been successfully employed to increase student engagement, participation and motivation [70]–[72]. Denny investigated the impact of incorporating badge-based achievement systems in an online learning tool for students and concluded that students were motivated to earn badges and also indicated a strong preference for having them displayed in the user interface [70]. Fitz-Walter et al. investigated the use of game achievements within Orientation Passport, a mobile application designed to help university students learn about their campus during the orientation phase of the semester [71]. Orientation Passport utilizes game achievements to present orientation information in an engaging way and to encourage the students to visit and learn about various places in the university. Gamification has been proven to enhance the quality of learning by better engaging students in learning activities. GamiCAD is a gamified tutorial system for AutoCAD users with real-time audio and video feedback. Users reported faster task completion time and found the experience to be more effective, engaging and enjoyable with the gamified version of the tutorial [73]. Quick Quiz, a gamified multiple-choice quiz application used by students reported a positive feedback in terms of learning effectiveness, engagement and enjoyment generated by the gamified application [74].

In health and wellness, gamification has been able to achieve high compliance and improved quality of life by motivating the users [75], [76]. Rose et al. studied the effects of a gamified mobile diabetes monitoring application called mySugr, on the compliance behavior of people with diabetes [75]. Results showed positive engagement of patients in testing frequency and blood sugar level, and quality of life was subjectively reported to have increased. Stinson et al. developed Pain Squad, a game-based smartphone pain assessment tool for adolescents with
cancer [76]. The game-based nature of the application was found to be appealing overall and the built-in virtual reward system was well received by the adolescents leading to high compliance and satisfaction scores. Another successful application of gamification is in the field of crowdsourcing. UbiAsk, a mobile crowdsourcing application designed for image based social search across languages, demonstrated the use of gamification based incentive system (points and leaderboards) to motivate users’ active participation and engagement [77]. The study showed significant improvement in terms of response speed and response quantity of its users. Prior research indicates that gamification can also be implemented to ensure sustainability of resources. A study by Gustafsson et al showed that, Power Agent, a mobile pervasive game connected to the users’ energy meters can be used as a powerful tool to both motivate and educate teenagers and their families towards energy conservation at home [78]. In a demand dispatch system, consumers should become encouraged to cover as much of their everyday energy demand as possible with timely flexibilities and define these flexibilities as long as possible. Gnauk et al. developed a real-time, human-controlled energy management system called MIRABEL that uses gamification elements such as points and leaderboards in place of traditional monetary incentives to motivate consumers for a sustainable participation in this system [79]. Gamification has also been successfully employed in commerce [80], workplace [81] and innovation/ideation [82]. The above discussed research incorporated gamification into virtual environments in a way that increased the motivation of users to perform a particular task or achieve a goal. This thesis investigates the elements of gamification behind this successful motivation and engagement of users.
2.2.2 Game Design Elements

The main ingredients of gamification are game design elements, which describe the specific and characteristic components of games that can be applied in gamification. According to Werbach and Hunter, there are three categories of game elements that are relevant to gamification: Dynamics, Mechanics and Components [83]. The authors define the three categories of game elements as follows:

- “Dynamics are the big-picture aspects of the gamified systems that you have to consider and manage but which you never directly enter into the game. Analogies in the management world would be employee development, creating an innovative culture, etc.
- Mechanics are the basic processes that drive the action forward and generate player engagement.
- Components are the specific instantiations of mechanics or dynamics”

Table 2-2 shows the list of game mechanics defined by [83] and relevant literature for successful implementation of each game element. For instance, Dong et al. used ‘challenge’ as a game element to teach users advanced image manipulation tasks in a software [84]. Downes-Le Guin et al. conducted an experiment comparing four styles of presenting a questionnaire: text only, decoratively visual, functionally visual, and gamified [85]. The gamified version featured the game design element ‘rewards’ and was found to produce greater overall satisfaction from participants.
Table 2-2: Literature on Game Mechanics

<table>
<thead>
<tr>
<th>Mechanical Game Design Elements</th>
<th>Relevant Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Challenges</strong> – Puzzles or other tasks that require effort to solve</td>
<td>[81], [84], [86]</td>
</tr>
<tr>
<td><strong>Chance</strong> – Involvement of luck from a random mechanism</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Competition</strong> – Getting players to compete against one another</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Cooperation</strong> – Getting players to work together to achieve a shared goal</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Feedback</strong> – Information about how the player is doing</td>
<td>[73], [78], [84]</td>
</tr>
<tr>
<td><strong>Resource acquisition</strong> – Obtaining useful or collectible item</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Rewards</strong> – Some benefits that go together for some action or achievement in the game</td>
<td>[73], [77], [85]</td>
</tr>
<tr>
<td><strong>Transactions</strong> – Buying, selling or trading with other human players or automated players</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Turns</strong> – Sequential participation by alternating players</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Win states</strong> – The state that defines winning the game</td>
<td>N/A</td>
</tr>
</tbody>
</table>

N/A – Not Available

Table 2-3 shows the list of game components defined by [83] and relevant literature for successful implementation of each game element. For example, Anderson et al. showed that users were observed to increase their effort levels when they were getting close to the contribution level required for a badge in StackOverflow (a question-answering website) [87]. Halan et al. found leaderboard as one of the effective motivation strategies to increase user participation in the conversational modeling for virtual humans [88].
Table 2-3: Literature on Game Components

<table>
<thead>
<tr>
<th>Component Game Design Elements</th>
<th>Relevant Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Achievements</strong> – A form of reward attached to performing specific actions</td>
<td>[71], [77], [89]</td>
</tr>
<tr>
<td><strong>Avatars</strong> – Visual representations of players’ characters</td>
<td>[75], [77], [85], [90]</td>
</tr>
<tr>
<td><strong>Badges</strong> – Visual representations of achievements</td>
<td>[70], [86], [87], [91]</td>
</tr>
<tr>
<td><strong>Boss Fights</strong> – Hard challenges at the culmination of a level</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Collections</strong> – Set of items or badges to accumulate</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Content unlocking</strong> - Unlocks new levels/new features when players reach specific objectives</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Gifting</strong> – Gives an opportunity to gift things such as lives/points to other players</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Leaderboards</strong> – Visual displays of player progression and achievements</td>
<td>[79], [86], [88]</td>
</tr>
<tr>
<td><strong>Levels</strong> – Defined steps in player progression</td>
<td>[84], [86], [92]</td>
</tr>
<tr>
<td><strong>Points</strong> – Numerical representation of game progression</td>
<td>[88], [92], [93]</td>
</tr>
<tr>
<td><strong>Quests</strong> – Predefined challenges with objectives and rewards</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Social graph</strong> – Ability to track progress of friend and enable interaction</td>
<td>[94]–[96]</td>
</tr>
<tr>
<td><strong>Teams</strong> – Group of players working towards a common goal</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Virtual Goods</strong> – Game assets with perceived or real money value</td>
<td>N/A</td>
</tr>
</tbody>
</table>

N/A – Not Available

“The motivational properties of these game design elements can be layered on top of other learning activities, integrating the human desire to communicate and share accomplishment with goal-setting to direct the attention of learners and motivate them to action” [97]. Since there is a
wide array of game design elements available, it makes it challenging for the VR developers to incorporate every game design element into a single virtual environment. Therefore, once the differences in performance outcomes between immersive and non-immersive VR environments are established, the author explores the game design elements that could be potentially integrated into virtual environments to make them more engaging and motivating for users.
Chapter 3

Methodology

The methodology presented in this thesis will i) explore whether there exists statistically significant differences in performance between users in immersive VR and non-immersive VR environments and then ii) explore video game design elements in non-game contexts (i.e., immersive VR environments) to motivate and increase user engagement, otherwise known as “gamification”. (Figure 3-1)

3.1 Investigating the Difference between Immersive and Non-Immersive VR System

With multiple research demonstrating the efficiency of non-immersive VR technologies in education, this thesis will investigate the efficiency of immersive VR technologies in comparison to non-immersive VR technologies. Though non-immersive VR or desktop VR systems are less
expensive to implement, it is considered as one of the least immersive implementations of VR techniques since the virtual environment is viewed only through a flat screen monitor. On the other hand, immersive VR provides a more immersive and realistic experience by placing the user into a virtual environment that looks and feels closer to the real world. Other notable advantages of immersive VR are its ability to enhance the perception of depth, sense of space and interaction with three dimensional objects. This section outlines a methodology to evaluate the differences in performance between individuals in immersive VR and non-immersive VR systems (Figure 3-2).
systems, the virtual environment continually adjusts to retain the viewer’s perspective. Immersive VR systems such as the head-mounted displays can track the users’ translational motions (x,y,z) as well as the rotational motions (yaw, pitch, roll), thereby allowing tracking in 6 degrees of freedom [Figure 3-3].

![Figure 3-3: Six Degrees of Freedom Achieved Using Immersive VR Systems](image)

_Hypothesis to Test the Efficiency of Users in Immersive VR Systems_

In VR research, task completion time has been used as a performance metric to evaluate the efficiency of users in VR systems. Jennett et al. showed that immersion can be measured subjectively (through questionnaires) as well as objectively (task completion time, eye
movements) [98]. Lendvay et al. used task completion time as one of the metrics to show that preoperative robotic warm-up using VR systems enhanced robotic task performance among surgeons [99]. Newmark et al. used task completion time to study the correlation in the assessment of laparoscopic surgical skills between medical students using a VR laparoscopic trainer and a low-fidelity video box trainer [100]. In an attempt to assess the feasibility of VR with hand-held devices, Hwang et al. evaluated the effectiveness of different VR platforms using task completion time in one of their experiments [101]. Ni et al. found that large display size i.e. large field of view and resolution (number of pixels) have a significant effect on the time taken to complete a task in information rich virtual environments [102]. Since immersive VR systems generally possess better field of view and resolution, this research will explore whether they have a significant impact on the task completion time in engineering related design activities such as product functional analysis.

**Null Hypothesis \( H_0 \):** *Time taken by students to complete the product functional analysis task using immersive VR system and non-immersive VR system are identical*

**Alternative Hypothesis \( H_a \):** *Time taken by students to complete the product functional analysis task using immersive VR system is less than the time taken by the students to complete the same activity using non-immersive VR system*

If the null hypothesis is rejected, it can be argued that immersive VR systems are better than the non-immersive VR systems in terms of efficiency to perform a given task. A case study involving 54 students in a product functional analysis task is presented in Section 4.1 to test this hypothesis.
3.2 Identification of Successful Game Design Elements

Games can be powerful experiences, leveraging both motivation and engagement [103]. Success of a game depends on its ability to motivate and engage people [21], [104], [105]. The successful game design elements when identified, could be incorporated into virtual environments to motivate and engage users to perform a specific task or goal. The game design elements built into the games that contribute towards their respective success (i.e. game design elements which are responsible for motivating and engaging users) are identified by mining game related features (Figure 3-4).

\begin{itemize}
  \item **Step 1**: Identify ‘m’ Game Design Elements
  \item **Step 2**: Select the Game Platform and ‘n’ Sample Games
  \item **Step 3**: Collect Data – Binary Input on the Presence or Absence of the Game Design Element in the Game
  \item **Step 4**: Construct the Confusion Matrix (Presence/Absence of the Game Design Element vs. Success/Failure of the Game) and Calculate F Score
  \item **Step 5**: Validation – Construct the Confusion Matrix (Presence/Absence of the Game Design Element vs. Positive/Negative Sentiment Towards the Game) and Calculate F Score
  \item **Step 6**: Compare the results from Step 4 and 5
\end{itemize}

Figure 3-4: Methodology to Identify Successful Game Design Elements
In step 1, the \( m \) game design elements to be studied are selected. List of different game
design elements is given in Table 2-2 and Table 2-3. In step 2, the platform and sample games are
chosen. There are various gaming platforms such as mobile, PC, console, etc. In the selected
platform, \( n \) games are selected. The \( n \) games can either be selected randomly or based on their
types (arcade, action, trivia, etc.) and then classified as successful or unsuccessful based on their
respective rankings. Step 3 involves constructing a \( n \times m \) binary input matrix based on the presence
or absence of each game design element (selected in step 1) in each game (selected in step 2) as
shown in Table 3-1. This \( n \times m \) matrix is obtained by mining features embedded in each game.

**Table 3-1: Representation of \( n \times m \) Matrix (Step 3)**

<table>
<thead>
<tr>
<th>Games</th>
<th>Game Design Element 1</th>
<th>Game Design Element 2</th>
<th>………</th>
<th>Game Design Element m</th>
<th>Successful vs. Unsuccessful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game 1</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>………</td>
<td>ABSENT</td>
<td>SUCCESSFUL</td>
</tr>
<tr>
<td>Game 2</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>………</td>
<td>PRESENT</td>
<td>UNSUCCESSFUL</td>
</tr>
<tr>
<td>Game 3</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>………</td>
<td>ABSENT</td>
<td>SUCCESSFUL</td>
</tr>
<tr>
<td>Game 4</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>………</td>
<td>ABSENT</td>
<td>UNSUCCESSFUL</td>
</tr>
<tr>
<td>Game n</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>………</td>
<td>ABSENT</td>
<td>UNSUCCESSFUL</td>
</tr>
</tbody>
</table>

The concept of confusion matrix analysis is used to evaluate the relationship between the
presence of a game design element and the games’ success. Table 3-2 illustrates a confusion matrix
where the columns represent the presence and absence of a particular game design element and the rows represent the games’ success which is determined based on their ranking.

Table 3-2: Confusion Matrix – Game Design Element vs. Success of Game (Step 4)

<table>
<thead>
<tr>
<th>SUCCESS OF THE GAME</th>
<th>GAME DESIGN ELEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUCCESSFUL</td>
<td>PRESENT</td>
</tr>
<tr>
<td>TRUE POSITIVE (TP)</td>
<td>FALSE POSITIVE (FP)</td>
</tr>
<tr>
<td>UNSUCCESSFUL</td>
<td>False Negative (FN)</td>
</tr>
</tbody>
</table>

Precision and Recall are the two commonly used metrics to evaluate relevance. Precision is the proportion of the predicted positive cases that were correct. In the context of relevance between the presence of a game design element and games’ success, precision can be defined as the ratio of the number of successful games which have a game design element to the total number of successful games with and without that particular game design element.

\[
Precision = \frac{True \ Positive}{True \ Positive + False \ Positive} \quad (3.1)
\]

Recall is the proportion of positive cases that were correctly identified. In the context of relevance between the presence of a game design element and games’ success, recall can be defined as the ratio of the number of successful games which have a game design element to the total number of successful and unsuccessful games with that particular game design element.

\[
Recall = \frac{True \ Positive}{True \ Positive + False \ Negative} \quad (3.2)
\]
Both Precision and Recall are usually expressed as a percentage. The F-score is another metric that characterizes the combined performance of both precision and recall. It is the harmonic mean of precision and recall.

\[
F\text{ Score} = 2 \left( \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \right)
\]  

(3.3)

In step 4, the confusion matrix is built and F-score is calculated for each game design element, thus establishing the relevance between the success of the game and the presence of the game design element. In order to validate the results of step 4, another confusion matrix is built in step 5 to establish the relevance between the presence of the game design element and the users’ sentiment towards the game. Finally, results obtained in step 4 and step 5 are compared. The proposed methodology will investigate the differences in performance outcomes using immersive and non-immersive VR environments based on task completion time and then, identify the game design elements that make such virtual environments motivating and engaging. Case studies to illustrate the methodology are presented in the next chapter.
Chapter 4
Case Studies and Discussion

The first section of this chapter discusses a case study involving 54 students in a product functional analysis task to test the hypothesis that immersive VR environments enhance performance outcomes when compared to non-immersive VR environments. Once the efficiency to perform a task in immersive and non-immersive VR environments are compared, the second section presents a case study involving 60 games from the Android market to identify the game design elements that make such virtual environments motivating and engaging. Figure 4-1 shows the integration of case studies with the proposed methodology.

Figure 4-1: Overall Methodology with Case Studies
4.1 Case Study 1: Product Functional Analysis

This section tests the hypothesis outlined in Section 3.1 by conducting an experiment involving 54 students in a product functional analysis activity. Product functional analysis, whether it is product dissection or assembly, is an integral part of understanding the engineering design process that has been shown to enhance students’ understanding of products, their components, and the interactions that exist between them [106]–[109]. Bohm and Stone have created advanced design repository systems for virtual product representations [110]. Devendorf and Lewis have explored the use of digital product repositories in enhancing product functional analysis activities [107]. Vasudevan and Tucker proposed an approach to digitally represent physical design artifacts using low cost 3D scanning techniques [111]. The experiment presented in this thesis advances the research on virtual product analysis in engineering design by investigating whether immersive VR systems enhance students’ performance in product functional analysis tasks, beyond the traditional non-immersive approaches to virtual prototyping and design. In this study, a product functional analysis is performed by two different groups of students, where one group uses an immersive VR system and another group uses a non-immersive VR system. The non-immersive VR group uses a game joystick to perform the activity in the virtual environment by looking at the computer desktop and the immersive VR group uses the same game joystick along with a 360 degree visual immersive tool (Oculus Rift®) to perform the same task in the same virtual environment. The specific product functional analysis task is to assemble the components of a coffee maker in the correct manner, given a baseline coffee maker as a reference model.
4.1.1 Research Environment

This study was carried out in the Design Analysis Technology Advancement (D.A.T.A) Laboratory at Penn State University. A total of six work stations were set up for the study with three of them allocated to immersive VR systems and the other three allocated to non-immersive VR systems. Figure 4-2 shows the laboratory setup of immersive VR systems.

![Laboratory Setup of Immersive VR System (Oculus Rift®)](image)

Figure 4-2: Laboratory Setup of Immersive VR System (Oculus Rift®)

4.1.2 Virtual Reality Setup – Hardware, Software and Environment

**Hardware**

Oculus Rift® is an immersive VR head-mounted display, being developed by Oculus VR®. It allows the users to be immersed in a three-dimensional environment. The set of lenses on the device create a stereoscopic 3D image and the external position tracking accessory tracks the movement of an individuals’ head accurately, which together, creates a 3D environment for the
user (Figure 3-3). Recent studies have shown that Oculus Rift® can be used as a suitable VR tool in education. [112], [113]. Oculus Rift Development Kit 2 with a resolution of 960 X 1080 per eye was used for the purpose of this study. Afterglow Wired Controller for Xbox 360 (PL 3702) was used as the joystick to interact with the objects in the virtual environment. The workstation was configured with an Intel® Core™ i5 – 4690 CPU @ 3.5 GHz processor and 8GB RAM.

**Software**

The virtual environment for the study was created by researchers in the D.A.T.A lab using Unity 4 (Version 4.6.1f1). Unity is a cross-platform game creation system which includes a game engine and an integrated development environment [114]. It is a flexible system which can be used to develop video games for websites, desktop platforms, consoles and mobile devices, and supports over fifteen platforms. Additionally, it is particularly popular in the independent game development and research community due to its low cost and ease of use.

**Environment**

The VR environment consisted of a classroom environment with a work table, on which the students had to perform the product functional analysis activity. The product used in this case study was a coffeemaker. The students had to look at the model coffee maker at the right and build a similar coffee maker using components on the left. Figure 4-3 shows the VR environment used for the product functional analysis task and Figure 4-4 shows the left and right eye images of the same VR environment in Oculus Rift®.
Figure 4-3: VR Environment of the Product Functional Analysis Task

Figure 4-4: Left and Right Eye Images of the VR Environment in Oculus Rift®
4.1.3 Experimental Study

This study was conducted in accordance with Penn State University’s Institutional Review Board (IRB) under protocol ID #1698 titled “The Digital Divide: Investigating Virtual Reality Technologies That Help Bridge the Gap Between Virtual and Brick & Mortar Learning”.

**Study Sample**

54 engineering undergraduate students in different class standings (freshmen, sophomore, junior and senior) were recruited by advertisement in the university campus, and assigned randomly to one of two groups. Group 1 (29 students) participated in the product functional analysis activity using immersive VR system (Oculus Rift) and Group 2 (25 students) participated in the same activity using a non-immersive VR system. In terms of gender, 47 were male (87%) and 7 were female (13%). Ages ranged from 17-27 years, the mean age being 19.85 years (Standard deviation = 1.62). 50 students (93%) who participated in the study had at least 1-2 years of experience with joysticks and 24 students (83%) in group 1 were first time Oculus Rift® users.

**Study Design**

54 students were split into two groups in a random manner. Before the start of the actual product functional analysis task, both the groups were given a pre-experiment questionnaire where they had to answer questions about expected learning outcomes in VR systems. Then, the students were provided with an instruction manual on how to use the joystick. Ten minutes of training time was allotted for each student to get accustomed with the joystick and the actual virtual environment used in the experiment. Group 1 students performed the activity with the immersive VR system (Oculus Rift + Joystick as shown in Figure 4-5) and the Group 2 students used the non-immersive
VR system (Desktop Monitor + Joystick as shown in Figure 4-6) to perform the same activity. Each student was asked to repeat the activity three times, with an average used for their task completion time. The task completion time of each student was measured using a digital clock embedded within the VR environment itself that automatically started when students began the activity. Upon completion of the activity, the students were given a post-test questionnaire with the same set of questions in the pre-experiment, which they now answered based on their VR experience. In the pre-experiment and post-experiment questionnaire the students were asked to circle a response ranging from 1 to 5 that best characterizes how they feel about each statement given in the questionnaire, where 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree Nor Disagree, 4 = Agree, and 5 = Strongly Agree (5 Point Likert Scale). The questionnaire used in this study is attached in the Appendix.

Figure 4-5: Student Using Immersive VR System (Oculus Rift®)
4.1.4 Study Results

The statistical analysis was carried out using Minitab 17. From Table 4-1, it can be observed that median task completion time of students using the immersive VR system is lesser than that of students using non-immersive VR system. The median difference in task completion time between the immersive and non-immersive VR group was -24.35 with 95% confidence intervals for the median difference in completion time of -48.63 to -10.93. Box plot shown in Figure 4-7 summarizes the results of task completion time obtained from both the groups. The center line of the box with the dark circle shows the median completion time, the dark triangle denotes the mean completion time, the box itself indicates the 25th percentile and 75th percentile and the ‘tails’ specify the 10th and 90th percentile.
Table 4-1: Median Task Completion Time of Two Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Median Completion Time (in Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: Immersive VR System</td>
<td>29</td>
<td>23.21</td>
</tr>
<tr>
<td>Group 2: Non-Immersive VR System</td>
<td>25</td>
<td>49.04</td>
</tr>
</tbody>
</table>

Figure 4-7: Box Plot Comparing Task Completion Time of Two Groups

Since the completion time was not normally distributed, the completion time of both groups were compared non-parametrically using Mann-Whitney U Test. The p-value obtained in the test was 0.0001 and since p-value is much lesser than 0.05, the null hypothesis is rejected and concluded that there is strong evidence to indicate that time taken by students to complete the activity using immersive VR system is less than the time taken by the students to complete the same activity using non-immersive VR system. Hence, the performance outcomes of the students
using immersive VR systems are found to be significantly better than students using non-immersive VR systems.

For the purpose of this study, two statements from the post-experiment questionnaire were used to investigate the preferences of students towards using immersive VR systems versus non-immersive VR systems in engineering design education. The students were asked to circle a response on the 5 point Likert scale for the statements.

**Statement 1:** *I find it useful to be able to virtually manipulate objects when I am doing engineering design*

![Bar chart](Image)

**Figure 4-8: Students Response to Statement 1 in Post-Experiment Questionnaire**

Figure 4-8 shows that, after participating in the experiment, a greater % of Group 1 (Immersive VR) students ‘Strongly Agreed’ with statement 1 when compared to Group 2 (Non-
immersive VR). Also, none of the Group 1 students ‘Disagreed’ with the statement as opposed to 8% of Group 2. But the pattern is reversed in the case of ‘Agreed’.

**Statement 2: I find it easier learning when I am virtually manipulating objects**

![Figure 4-9: Students Response to Statement 2 in Post-Experiment Questionnaire](image)

Figure 4-9 shows that after participating in the experiment, a greater % of Group 1 (Immersive VR) ‘Strongly Agreed’ or ‘Agreed’ with statement 2 when compared to Group 2 (Non-immersive VR). The pattern is reversed in the other cases. Overall, Figures 4-8 and 4-9 demonstrate a positive feedback in terms of students’ attitude towards learning using immersive VR systems in comparison to non-immersive VR systems.

Another two statements from the questionnaire of students who participated using immersive VR system (Group 1) were analyzed to understand the interest of students towards using immersive virtual reality technologies in classrooms.
**Statement 3:** Virtual reality technology such as Oculus Rift® can be useful as a classroom tool

**Statement 4:** I will be interested to enroll in a class which uses virtual reality technology such as Oculus Rift®

![Image of bar chart showing student responses to Statements 3 and 4]

**Figure 4-10: Group 1 (Immersive VR System) Students Response to Statement 3 and 4**

Figure 4-10 demonstrates the significant interest of students towards using immersive VR technology as a classroom tool. At the end of the post-experiment questionnaire, all students were asked to briefly describe their experience of interacting with objects in virtual world versus the real world. Some of the feedback obtained from Group 1 students who used immersive VR system are discussed below:

1) 24% of the students felt that the use of joystick made the experience less realistic and few of them proposed that it would be more realistic if they could use their hands to interact with the objects in the virtual environment.
2) Though most of the students felt that the immersive VR experience was very realistic, 7% of them reported to have trouble in estimating the depth of objects.

3) 7% of students who used the immersive VR system reported motion sickness.

About 32% of Group 2 students who used non-immersive VR system reported having difficulty using the joystick to interact with virtual objects. Contrastingly, only 14% of Group 1 students reported such difficulties. This may be due to the fact that non-immersive VR system does not continually adjust to retain the viewers’ perspective unlike immersive VR system. This could be a contributing factor towards significant difference in task completion time between the two groups.

4.2 Case Study 2: Mining Features of Android Games

The case study presented in the previous section supported the hypothesis that students using immersive VR system complete a task in less time when compared to students using non-immersive VR system. Now that it has been determined that the immersive VR system is better in terms of task performance, the game design elements which will encourage the users to adopt such VR systems are explored. This section illustrates the proposed methodology in Section 3.2 using 60 games from the Android market. Each step of the methodology is explained in detail.

4.2.1 Step 1 – Selection of Game Design Elements

As explained earlier, game dynamics are big-picture aspects of the gamified systems and cannot be directly entered into the game. Therefore 10 game mechanic elements and 14 game
component elements given in Table 2-2 and Table 2-3 respectively, are considered for the purpose of this study (m = 24).

4.2.2 Step 2 – Selection of Platform and Sample Games

In this study, the mobile platform is considered since it is used across different age and gender demographics when compared to other gaming platforms such as Consoles and PCs. According to a recent report by NPD group, 71% of U.S gamers are using mobile phones to play video games and it also reported that mobile is the only type of gaming device to exhibit year-over-year growth in usage [115]. The mobile gaming population is known to be very frequent gamers i.e., 60% play games at least once per day [116]. Android is one of the most popular mobile platforms for gaming. According to Gartner, “in the operating system (OS) market, Android surpassed a billion shipments of devices in 2014, and will continue to grow at a double-digit pace in 2015, with a 26 percent increase year over year” [117]. Therefore, games from the Android market were selected for this study. The rankings provided by the Android market are considered as the basis for classifying games as successful or unsuccessful. The rankings of games on the Android market are classified into three categories namely, ‘Top Free Games’, ‘Top Grossing Games’ and ‘Top Paid Games’. Android market displays 540 games under each category where the games ranked in the top are successful and games ranked in the bottom are less successful. For the purpose of this study, the top 10 and bottom 10 ranked games of all three categories are considered as shown in Figure 4-11 (n = 60). The bottom 10 ranked games are referred to as “less successful”, instead of “unsuccessful” since they have featured in the top 540 ranked games among thousands of games in the Android market.
4.2.3 Step 3 – Data Collection

The binary matrix (60X24) was obtained by manually mining game design elements embedded in each game. Sample data are shown in Table 4-2.

Table 4-2: Sample Data Collected

<table>
<thead>
<tr>
<th>Games</th>
<th>Challenges</th>
<th>Chance</th>
<th>...</th>
<th>Teams</th>
<th>Virtual Goods</th>
<th>Successful vs. Less Successful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game 1</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>...</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>SUCCESSFUL</td>
</tr>
<tr>
<td>Game 2</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>...</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>SUCCESSFUL</td>
</tr>
<tr>
<td>Game 3</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>...</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>SUCCESSFUL</td>
</tr>
<tr>
<td>Game 58</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>...</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>LESS SUCCESSFUL</td>
</tr>
<tr>
<td>Game 59</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>...</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>LESS SUCCESSFUL</td>
</tr>
<tr>
<td>Game 60</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>...</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>LESS SUCCESSFUL</td>
</tr>
</tbody>
</table>
4.2.4 Step 4 – Confusion Matrix - Game Design Element vs. Success of Game

Confusion matrix evaluating the relevance between the presence of a game design element and the games’ success is constructed for each game design element using the data from Table 4-2. A sample confusion matrix for one of the game design elements (challenge) is shown in Table 4-3.

Table 4-3: Confusion Matrix – Presence of 'Challenge' vs. Success of Game

<table>
<thead>
<tr>
<th>SUCCESS OF THE GAME</th>
<th>SUCCESSFUL</th>
<th>LESS SUCCESSFUL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESENT</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>ABSENT</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

From Table 4-3, the following can be inferred:

- 28 games having ‘challenge’ as a game design element are successful
- 22 games having ‘challenge’ as a game design element are less successful
- 2 games not having ‘challenge’ as a game design element are successful
- 8 games not having ‘challenge’ as a game design element are less successful

Precision, recall and F-Score of ‘challenge’ is calculated as shown below:

Precision = \[ \frac{True \ Positive}{True \ Positive + False \ Positive} = \frac{28}{28+2} = 0.9333 \text{ or } 93.33\% \]

Recall = \[ \frac{True \ Positive}{True \ Positive + False \ Negative} = \frac{28}{28+22} = 0.5600 \text{ or } 56.00\% \]

\[ F - Score = 2 \left( \frac{Precision \times Recall}{Precision + Recall} \right) = 0.7000 \]

Similarly the confusion matrix was constructed and F-score was calculated for all the 24 game design elements. Summary of F-scores are presented in Table 4-4.
Table 4-4: Summary of Precision, Recall and F-score at Step 4

<table>
<thead>
<tr>
<th>Game Design Element</th>
<th>Precision</th>
<th>Recall</th>
<th>F-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge</td>
<td>0.933</td>
<td>0.560</td>
<td>0.700</td>
</tr>
<tr>
<td>Chance</td>
<td>0.500</td>
<td>0.652</td>
<td>0.566</td>
</tr>
<tr>
<td>Competition</td>
<td>0.333</td>
<td>0.625</td>
<td>0.435</td>
</tr>
<tr>
<td>Cooperation</td>
<td>0.133</td>
<td>0.800</td>
<td>0.229</td>
</tr>
<tr>
<td>Feedback</td>
<td>0.733</td>
<td>0.595</td>
<td>0.657</td>
</tr>
<tr>
<td>Resource Acquisition</td>
<td>0.500</td>
<td>0.441</td>
<td>0.469</td>
</tr>
<tr>
<td>Rewards</td>
<td>0.667</td>
<td>0.513</td>
<td>0.580</td>
</tr>
<tr>
<td>Transaction</td>
<td>0.500</td>
<td>0.556</td>
<td>0.526</td>
</tr>
<tr>
<td>Turns</td>
<td>0.167</td>
<td>0.625</td>
<td>0.263</td>
</tr>
<tr>
<td>Win States</td>
<td>0.667</td>
<td>0.526</td>
<td>0.588</td>
</tr>
<tr>
<td>Achievements</td>
<td>0.433</td>
<td>0.382</td>
<td>0.406</td>
</tr>
<tr>
<td>Avatars</td>
<td>0.567</td>
<td>0.567</td>
<td>0.567</td>
</tr>
<tr>
<td>Badges</td>
<td>0.100</td>
<td>0.429</td>
<td>0.162</td>
</tr>
<tr>
<td>Boss Fights</td>
<td>0.133</td>
<td>0.400</td>
<td>0.200</td>
</tr>
<tr>
<td>Collection</td>
<td>0.433</td>
<td>0.500</td>
<td>0.464</td>
</tr>
<tr>
<td>Content Unlocking</td>
<td>0.633</td>
<td>0.576</td>
<td>0.603</td>
</tr>
<tr>
<td>Gifting</td>
<td>0.367</td>
<td>0.688</td>
<td>0.478</td>
</tr>
<tr>
<td>Leaderboards</td>
<td>0.667</td>
<td>0.606</td>
<td>0.635</td>
</tr>
<tr>
<td>Levels</td>
<td>0.667</td>
<td>0.500</td>
<td>0.571</td>
</tr>
<tr>
<td>Points</td>
<td>0.833</td>
<td>0.676</td>
<td>0.746</td>
</tr>
<tr>
<td>Quests</td>
<td>0.200</td>
<td>0.545</td>
<td>0.293</td>
</tr>
<tr>
<td>Social Graph</td>
<td>0.667</td>
<td>0.541</td>
<td>0.597</td>
</tr>
<tr>
<td>Teams</td>
<td>0.067</td>
<td>0.400</td>
<td>0.114</td>
</tr>
<tr>
<td>Virtual goods</td>
<td>0.700</td>
<td>0.583</td>
<td>0.636</td>
</tr>
</tbody>
</table>

4.2.5 Step 5 – Confusion Matrix - Game Design Element vs. Game Sentiment

In order to validate the results obtained in the previous step, another confusion matrix is constructed by replacing the class variable of the previous step (success of the game) with the type of sentiment (positive or negative) expressed by the users towards the game. Textual data generated by the users provide the ability to quantify their sentiments [118]. Android market allows
users to post reviews of the games which are visible to public. A Java web crawler tool was developed to download the user reviews, but Android store policy seemed to restrict the automated download of user reviews using web crawler and constrained the web crawler to download only 500 user reviews. Therefore, instead of downloading the 500 ‘most recent’ user reviews, the web crawler was used to download the 500 ‘most useful’ user reviews for each game, which is assumed to be a better representation of the users’ sentiment towards the game. Using the downloaded user reviews, sentiment score was calculated for each game using a sentiment analysis tool (Alchemy API) on a scale of -1 to +1, where -1 denotes strong negative sentiment and +1 denotes strong positive sentiment. Once the numerical sentiment score was calculated for each game, they were converted into categorical sentiment value such as ‘Negative’ (sentiment score less than zero) and ‘Positive’ (sentiment score greater than zero). Sample data are shown in Table 4-5.

Table 4-5: Sample Data Collected - Sentiment Scores

<table>
<thead>
<tr>
<th>Games</th>
<th>Challenges</th>
<th>Chance</th>
<th>……</th>
<th>Teams</th>
<th>Virtual Goods</th>
<th>Sentiment Score</th>
<th>Sentiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game 1</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>……</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>-0.175</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>Game 2</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>……</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>-0.317</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>Game 3</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>……</td>
<td>ABSENT</td>
<td>PRESENT</td>
<td>-0.305</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>Game 58</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>……</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>0.048</td>
<td>POSITIVE</td>
</tr>
<tr>
<td>Game 59</td>
<td>PRESENT</td>
<td>PRESENT</td>
<td>……</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>-0.090</td>
<td>NEGATIVE</td>
</tr>
<tr>
<td>Game 60</td>
<td>PRESENT</td>
<td>ABSENT</td>
<td>……</td>
<td>ABSENT</td>
<td>ABSENT</td>
<td>0.057</td>
<td>POSITIVE</td>
</tr>
</tbody>
</table>
Confusion matrix evaluating the relevance between the presence of a game design element and the users’ sentiment towards the games is constructed for each game design element using the data from Table 4-5. A sample confusion matrix for one of the game design elements (challenge) is shown in Table 4-6.

**Table 4-6: Confusion Matrix – Presence of 'Challenge' vs. Game Sentiment**

<table>
<thead>
<tr>
<th>SENTIMENT TYPE</th>
<th>GAME DESIGN ELEMENT – ‘CHALLENGE’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRESENT</td>
</tr>
<tr>
<td>POSITIVE</td>
<td>22</td>
</tr>
<tr>
<td>NEGATIVE</td>
<td>28</td>
</tr>
</tbody>
</table>

From the Table 4-6, the following can be inferred:

- 22 games having ‘challenge’ as a game design element received positive sentiment score
- 28 games having ‘challenge’ as a game design element received negative sentiment score
- 6 games not having ‘challenge’ as a game design element received positive sentiment score
- 4 games not having ‘challenge’ as a game design element received negative sentiment score

Similarly the confusion matrix was constructed and F-score was calculated for all the 24 game design elements. Summary of F-scores are presented in Table 4-7.
Table 4-7: Summary of Precision, Recall and F-score at Step 5

<table>
<thead>
<tr>
<th>Game Design Element</th>
<th>Precision</th>
<th>Recall</th>
<th>F-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge</td>
<td>0.786</td>
<td>0.440</td>
<td>0.564</td>
</tr>
<tr>
<td>Chance</td>
<td>0.286</td>
<td>0.348</td>
<td>0.314</td>
</tr>
<tr>
<td>Competition</td>
<td>0.214</td>
<td>0.375</td>
<td>0.273</td>
</tr>
<tr>
<td>Cooperation</td>
<td>0.036</td>
<td>0.200</td>
<td>0.061</td>
</tr>
<tr>
<td>Feedback</td>
<td>0.500</td>
<td>0.378</td>
<td>0.431</td>
</tr>
<tr>
<td>Resource Acquisition</td>
<td>0.500</td>
<td>0.412</td>
<td>0.452</td>
</tr>
<tr>
<td>Rewards</td>
<td>0.607</td>
<td>0.436</td>
<td>0.507</td>
</tr>
<tr>
<td>Transaction</td>
<td>0.357</td>
<td>0.370</td>
<td>0.364</td>
</tr>
<tr>
<td>Turns</td>
<td>0.143</td>
<td>0.500</td>
<td>0.222</td>
</tr>
<tr>
<td>Win States</td>
<td>0.643</td>
<td>0.474</td>
<td>0.545</td>
</tr>
<tr>
<td>Achievements</td>
<td>0.679</td>
<td>0.559</td>
<td>0.613</td>
</tr>
<tr>
<td>Avatars</td>
<td>0.393</td>
<td>0.367</td>
<td>0.379</td>
</tr>
<tr>
<td>Badges</td>
<td>0.179</td>
<td>0.714</td>
<td>0.286</td>
</tr>
<tr>
<td>Boss Fights</td>
<td>0.179</td>
<td>0.500</td>
<td>0.263</td>
</tr>
<tr>
<td>Collection</td>
<td>0.429</td>
<td>0.462</td>
<td>0.444</td>
</tr>
<tr>
<td>Content Unlocking</td>
<td>0.500</td>
<td>0.424</td>
<td>0.459</td>
</tr>
<tr>
<td>Gifting</td>
<td>0.214</td>
<td>0.375</td>
<td>0.273</td>
</tr>
<tr>
<td>Leaderboards</td>
<td>0.500</td>
<td>0.424</td>
<td>0.459</td>
</tr>
<tr>
<td>Levels</td>
<td>0.679</td>
<td>0.475</td>
<td>0.559</td>
</tr>
<tr>
<td>Points</td>
<td>0.500</td>
<td>0.378</td>
<td>0.431</td>
</tr>
<tr>
<td>Quests</td>
<td>0.179</td>
<td>0.455</td>
<td>0.256</td>
</tr>
<tr>
<td>Social Graph</td>
<td>0.607</td>
<td>0.459</td>
<td>0.523</td>
</tr>
<tr>
<td>Teams</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Virtual goods</td>
<td>0.500</td>
<td>0.389</td>
<td>0.438</td>
</tr>
</tbody>
</table>

4.2.6 Step 6 – Comparison of Results

Comparing the top 10 game design elements with the highest F-scores in step 5 with that of step 4, it can be seen that 7 game design elements are identical, validating the results obtained in step 4. Figure 4-12 depicts the pictorial comparison of the results. Therefore, it can be concluded
that these 7 common game design elements (challenges, levels, win states, social graph, rewards, content unlocking and leaderboards) when incorporated individually into the game, have a higher probability of making a game successful, i.e., these games can successfully motivate and engage people.

The virtual environment used in the product functional analysis case study was analyzed for the presence of these seven successful game design elements identified. Since assembling the components of a coffee maker in the correct manner given a baseline coffee maker as a reference model requires certain effort to solve, based on the definition given in Table 2-2, it is concluded that the game design element ‘challenge’ was present in the virtual environment.

Figure 4-12: Comparison of Results
Chapter 5

Conclusions and Future Work

The first objective of this research was to investigate whether there exists statistically significant differences in performance outcomes between individuals engaged in non-immersive and immersive VR systems. A case study involving 54 students in a product functional analysis task was used to test the hypothesis that immersive VR systems enhance performance outcomes when compared to non-immersive VR systems and this hypothesis was supported (p-value = 0.0001). The median task completion time of students using the immersive VR system (23.21 seconds) was found to be lesser than that of students using non-immersive VR system (49.04 seconds). Therefore, the performance outcomes of the individuals using immersive VR systems are significantly better than individuals using non-immersive VR systems. Apart from the statistical test on the task completion time, the preference of students towards using VR systems in education was investigated. In general, positive feedback towards immersive VR systems was found among students. Most of the Group 1 participants who used Oculus Rift® reported that the experience of using immersive VR system was very realistic and interesting, but pointed out that the use of a joystick in the immersive VR system made their experience less realistic. This emphasizes on the necessity for exploring the integration of 3D interactive technology, such as a haptic glove, with immersive visual displays to achieve additional immersion. The other issues reported by the students using immersive VR systems were related to difficulty in perception of depth and motion sickness. Immersion is considered as one of the most important characteristics contributing towards the sense of presence experienced by the user in the VR system. Further
studies involving integration of immersive visual displays with 3D interactive devices are required. The 3D interactive devices when integrated with immersive visual displays have the potential to increase the level of presence among users. Apart from the technological characteristics like immersion, individual characteristics such as age and gender can also affect the level of presence experienced by users. Therefore, it would be interesting to conduct large scale studies to investigate the performance outcomes in immersive VR systems among users of different gender and age groups. In future, reasons for the observed difference in performance outcomes between individuals in immersive and non-immersive systems need to be explored. In this study, task completion time was used as a metric to evaluate the performance outcomes, future evaluation efforts could include other metrics beyond task completion time.

The second objective of this research was to identify the game design features of the virtual environments, such as those generated by immersive VR systems, to motivate and increase user engagement. Once immersive VR system users were determined to have better task performance outcomes than non-immersive VR system users, the game design elements which encourage the users to adopt immersive VR systems were explored. There is a need to design VR environments in such a way that they are inherently motivating in order to engage the users who are characterized by low interest or lack of motivation due to switch from one type of medium (for example, traditional brick and mortar classroom) to another (for example, virtual classroom). Video games being one of the most successful applications of virtual environments, the game design elements built into the video games which contribute towards their respective success (i.e. game design elements which are responsible for motivating and engaging users) were identified by mining game related features. A case study involving 60 games from the Android market was performed and
seven game design elements (challenges, levels, win states, social graph, rewards, content unlocking and leaderboards) were discovered to motivate users and maintain user engagement for extended periods of time. But it is to be noted that, this research studied only the relation between the presence of an individual game design element to the games’ success. It would be interesting to analyze the interaction effect of two or more game design elements on the games’ success, since interactions can have varying effects. One of the limitations of this study is that, it explored the game design elements in casual games on the mobile platform. In the future, similar studies using other types of games such as serious games could be performed. A significant future extension of this research would be to test the hypothesis that immersive VR systems that are ‘gamified’ using these game design elements are more effective in terms of motivating and engaging users when compared to non-gamified immersive VR systems.

Immersive VR systems could provide the potential platform for students to participate in learning activities remotely from their home or anywhere else, thereby facilitating distance education. Recent developments in technology and internet connectivity have dramatically increased the accessibility to education through Massive Open Online Course (MOOC) platforms. The ease of accessibility and quality of the course materials have in turn, increased the popularity of MOOCs [119]. MOOC predominantly utilizes videos, texts and images for learning purposes [120], [121]. Though there are several advantages of such platforms, the inability to deliver practical hands-on experience is seen as a major drawback, especially in technical courses associated with engineering. The immersive VR systems when integrated with MOOC platforms can possibly overcome this drawback. The confluence of rapid advancements in the hardware and software industry are in the verge of making remote VR education a practical reality.
If VR has the potential to perfectly simulate the real world by recreating all sensory experiences and modify or manipulate human behaviors, can VR learning environments successfully replace the traditional brick and mortar learning environments?

This is one of the most challenging questions which VR researchers in education and learning are trying to answer. This thesis is a small contribution towards answering that question.
Appendix

Product Functional Analysis - Experiment Questionnaire

Please note that this survey is anonymous so please provide honest and constructive feedback. Thank you!
Feel free to skip responses to certain questions if you are not comfortable answering it.

In which virtual reality activity did you participate?

- [ ] With Oculus Rift
- [ ] Without Oculus Rift

Section 1: Participant Information

1) What is your age? _______

2) What is your gender?  [ ] Male  [ ] Female

3) Ethnicity:  [ ] African American (non-Hispanic)  [ ] Asian/Pacific Islanders
   [ ] Caucasian (non-Hispanic)  [ ] Latino/Hispanic
   [ ] Native American  [ ] Other

4) Are you an engineering student?  [ ] Yes  [ ] No

5) What is your major? ________________

6) What is your minor? (if applicable) __________________

7) Class Standing?  [ ] Freshman  [ ] Sophomore  [ ] Junior  [ ] Senior  [ ] Graduate

8) How many years of experience do you have in using video game joysticks?
   [ ] Never  [ ] 1-2  [ ] 3-4  [ ] >5

9) How many times have you used Oculus Rift in the past?
   [ ] Never  [ ] 1-5  [ ] 6-10  [ ] >10
**Section 2: Pre-Experiment**

For each of the questions below, circle the response that best characterizes how you feel about the statement where,

1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree

<table>
<thead>
<tr>
<th>10) I find it useful to be able to <strong>physically</strong> touch and manipulate products when I am doing engineering design</th>
<th><strong>Strongly Disagree</strong></th>
<th><strong>Disagree</strong></th>
<th><strong>Neither Agree nor Disagree</strong></th>
<th><strong>Agree</strong></th>
<th><strong>Strongly Agree</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11) I find it easier learning when I am <strong>physically</strong> manipulating objects</th>
<th><strong>Strongly Disagree</strong></th>
<th><strong>Disagree</strong></th>
<th><strong>Neither Agree nor Disagree</strong></th>
<th><strong>Agree</strong></th>
<th><strong>Strongly Agree</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12) I find it useful to be able to <strong>virtually</strong> manipulate objects when I am doing engineering design</th>
<th><strong>Strongly Disagree</strong></th>
<th><strong>Disagree</strong></th>
<th><strong>Neither Agree nor Disagree</strong></th>
<th><strong>Agree</strong></th>
<th><strong>Strongly Agree</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13) I find it easier learning when I am <strong>virtually</strong> manipulating objects</th>
<th><strong>Strongly Disagree</strong></th>
<th><strong>Disagree</strong></th>
<th><strong>Neither Agree nor Disagree</strong></th>
<th><strong>Agree</strong></th>
<th><strong>Strongly Agree</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>14) The use of virtual tools and technologies hinder my learning</th>
<th><strong>Strongly Disagree</strong></th>
<th><strong>Disagree</strong></th>
<th><strong>Neither Agree nor Disagree</strong></th>
<th><strong>Agree</strong></th>
<th><strong>Strongly Agree</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

15) Briefly describe your perception of interacting with objects in the virtual world versus the real world?
Section 3: Post-Experiment

For each of the questions below, circle the response that best characterizes how you feel about the statement where,

1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>16) I find it useful to be able to <strong>physically</strong> touch and manipulate products when I am doing engineering design.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17) I find it easier learning when I am <strong>physically</strong> manipulating objects</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>18) I find it useful to be able to <strong>virtually</strong> manipulate objects when I am doing engineering design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>19) I find it easier learning when I am <strong>virtually</strong> manipulating objects</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>20) The use of virtual tools and technologies hinder my learning</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

21) Task Completion time:  
- Trial 1: _____  
- Trial 2: _____  
- Trial 3: _____

22) Briefly describe your experience of interacting with objects in the virtual world versus the real world?
Section 4: Post-Experiment Questions for Immersive VR Group

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>23) Virtual reality technology such as Oculus rift® can be useful as a classroom tool</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>24) Virtual reality technology such as Oculus rift® will help in better understanding of the engineering design concepts</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>25) I will be interested to enroll in a class which uses Virtual reality technology such as Oculus rift®</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
References


up improves task performance in a dry laboratory environment: a prospective randomized controlled study,” *Journal of the American College of Surgeons*, vol. 216, no. 6, pp. 1181–1192, 2013.


