VISTAS: VOCATIONAL IMMERSIVE STORYTELLING TRAINING AND SUPPORT FRAMEWORK FOR AUGMENTING WORK PERFORMANCE

by

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THIS BOOK IS DEDICATED TO MY VISIONARY MOTHER, BABITA GUPTA

AND TO THE LOVE OF MY LIFE, JAYESH DOOLANI

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ABSTRACT

VISTAS: VOCATIONAL IMMERSIVE STORYTELLING TRAINING AND SUPPORT FRAMEWORK FOR AUGMENTING WORK PERFORMANCE

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Training and assessment of novice workers are the most vital part of any vocational industry. Innovations in science and technology have led to the creation of new industries and occupations, enhanced productivity and quality of work-life, and increased the potential for more people to participate in the workforce. However, these come at the risk and disadvantage of an increased cost of training and lack of proper training in industries, such as manufacturing. Recently, the use of Extended Reality (XR) systems has been on the rise to tackle various domains such as training, education, safety, etc. With the recent advances in Augmented Reality (AR), Virtual reality (VR), and Mixed Reality (MR) technologies, the manufacturing industry has seen a rise in the use of advanced XR immersive technologies to train its workforce.

Working memory (short-term memory) and episodic memory (long-term memory) are mainly responsible for the process of learning, which is an essential aspect of training. On the other hand, storytelling has been established as a proven method to effectively communicate and assist in knowledge transfer. This research is motivated by the gap between Storytelling and Immersive technologies like VR/AR and how

they can be combined to form an effective training system, which maintains the level of engagement and immersion provided by immersive XR technology but also provides the core strengths of storytelling, thereby improving the episodic and working memory of the user.

To this end, we present VISTAS Framework - an intelligent, interactive. Immersive storytelling training and support framework to improve episodic and working memory enable personalized training and assessment to facilitate job readiness, well-being, safety, and low-cost training, using Reinforcement Learning methods to adapt the story and tasks the user's needs/performance. It uses storyfication in an immersive augmented reality workplace environment to train a new worker, support the worker while doing the task and then assess their performance. This framework has the capability to improve the workplace training process. By making it adaptive for various demographics and minorities, and with the help of intelligent learning algorithms, the framework can also be used for varying levels of complex training. To evaluate the framework's effectiveness, several user studies were conducted.

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CHAPTER 1

INTRODUCTION

Vocational training consists of instructional programs and courses to train a workforce. It focuses on training people with the skills required for a particular job function or trade. Manufacturing training is a subset of vocational training, where the worker is given on-the-job training to acquire or improve the skills required to do the job. Gennrich et al. [4] state that Technical and Vocational Education and Training (TVET) uses formal, non-formal, and informal learning methods to provide knowledge and skills required for the trade.

Manufacturing industries have drastically changed over the past few years. Traditionally, the manufacturing of goods has evolved from craftsmanship to highly organized mass-producing factories to highly customized Industry 4.0. Subsequently, the skills required by the workforce to adapt to these rapid changes have increased. Moreover, global competition drives manufactured goods nowadays, and there is a need for fast adaptation of skills, processes, and production to meet the transformative markets' requests.

Productivity has increased due to rapid advancements in manufacturing technologies. Hence, there is a need to ensure worker engagement, performance, and wellness. Industry 4.0 is referred to as IIoT and intelligent manufacturing. Physical development and operations are combined with smart digital technologies, machine learning, and big data to create a more comprehensive and integrated environment for manufacturing and supply chain management companies. The skills are needed for both cognitive and physical areas. There has been a very significant increase in skill demands because of the evolving manufacturing sector. For example, due to Industry 4.0, which includes Internet of Things (IoT), Industrial Internet of Things (IIoT), Cloud-based manufacturing, and smart manufacturing, which makes the manufacturing process digitized and intelligent, as described by Ero et al. [5], the demand for cognitive skills has increased. With close integration of technology, robots, automated factory lines, and intelligent manufacturing, the worker must use cognitive skills to work efficiently. Along with this, the cognitive load of workers is higher than ever, and there is a need to assess, monitor, and improve cognitive performance.

Newly required skills include, and are not limited to, understanding the complete manufacturing process, which starts from order to delivery of the product, working with smart devices at the factory, learning to use technically advanced machinery and tools, communicating with and handling robots, understanding how to read, understanding and conveying data in real-time, learning to program firm software, and working with data mining and cloud infrastructure. In addition, due to the rise of robotic technologies, the integration of smart connected robotics and smart maintenance is expected in Industry 4.0 [6].

The TVET systems need to prepare for the skills of the future for global connectivity and smart technologies in the manufacturing sector. Future and Jobs Reports of the World Economic Forum from 2015 list the top ten skills relevant for Industry 4.0. These are cross-functional skills, also known as soft/interpersonal skills. Even though these skills are not-job specific and remain highly common in every vocation, the importance of training the workers with these skills that improve their cognitive performance highly affects the overall outcome of the job.

In manufacturing, the skills are applied to produce marketable goods and products. The worker acquires the skills necessary to help produce these goods and products, and the process by which the worker develops the needed abilities is considered training. Currently, many manufacturing companies train their workers in different ways. One popular method is by assigning a senior member of the workforce to the new worker. This member acts as a mentor and teaches every skill needed to finish the job. Another standard method is enrolling the workers in a time-based curriculum, where they are taught the theory and practical versions of the skills. Both these methods are part of on-the-job training. The other version of manufacturing training is the one that is taught in trade schools or vocational training programs outside the companies. It is sporadic to see any standardization or consistency amongst these methods of training [7]. This causes the workers to learn one type of skill-specific to that manufacturing company, which means that they have few transferable cognitive skills. After the training, the worker may or may not give a test to assess how much they have learned over the training period. Moreover, these methods of training do not evolve as quickly as technological advancements in the manufacturing sector.

Workers in manufacturing environments must be trained and re-trained to meet the evolving market needs and ensure worker safety. This training should reflect the demands on their skills. Therefore, the workers' skills are directly related to their performance. The purpose of this dissertation is to focus on the need for worker training with advanced new immersive technologies that provide better global training, which in turn leads to the improvement of workers' cognitive performance in the manufacturing industry.

1.1 Motivation

There is an opportunity to create new industries and occupations, enhanced productivity and quality of work-life, and the potential for more people to participate in the workforce, ultimately yielding sustained innovation and global leadership. The risks are jobs lost to automation or demand for skills not met by current educational pathways, new security threats, algorithmic biases, unanticipated legal consequences including privacy implications, dependence on technology and erosion of human knowledge and skills, inadequate workplace policies and practices, or undesirable impact on the built environment. This dissertation aims to understand and develop the human-technology partnership and design new technologies to augment human performance.

1.1.1 Increased demand of training

One of the most important factors behind a country's rising poverty and unemployment has been tied to the population's skill level and its ability to gain new skills in this changing technological landscape. The first response of policymakers to this has been launching new vocational training initiatives to upgrade the skill level of its population, especially the youth [8, 9]. However, employers invest an average of $3,000,000 per year to upgrade the skills of their workforce [10], primarily by assigning mentors to oversee the training. Hence, the need for a cheap training replacement that offers the same training level has been the need of the hour.

Researchers have worked extensively on producing innovative computer-based techniques to train and prepare workers for various positions in the industry to tackle this problem. As a result, a meteoric rise was seen in Human-Robot-Interaction (HRI) based applications [11, 12, 13, 14] and Augmented and Virtual Reality (AR/VR) applications [15, 16] targeted towards teaching new skills - vocational or otherwise.

While HRI and AR-based vocational training do require a user to be physically present in an environment for which the training is curated, VR, on the other hand, offers an entirely different experience wherein a user could be wholly immersed in a virtual simulation of the same environment. This immersive capability of Virtual Reality systems has been found to enhance engagement [17, 18, 19] and cognitive capabilities, such as recall [20, 21, 22]. However, while such applications do succeed in imparting new skills [23], they fail to provide the social and emotional interaction experience that comes from undertaking the same training in person on-site.

From a sociological viewpoint, a growing need and acceptance of interactive digital storytelling technologies have become ubiquitous [24, 25]. At its core, digital storytelling allows computer users to become creative storytellers through the traditional processes of selecting a topic, conducting some research, writing a script, and developing an exciting story. In addition, a story can be curated in the form of a personal narrative focusing on educational content.

1.1.2 Need for Extended Reality (XR) in Manufacturing Training

Extended reality (XR) refers to all natural and virtual environments combined, where the interaction between human and machine occurs through interactions generated by computer technology and hardware. XR technologies consist of virtual reality (VR), mixed reality (MR), and augmented reality (AR). Figure 1.1 shows the reality-virtuality continuum adopted from Milgram et al. [1], which gives an overview of the XR ecosystem and how VR/AR/MR relates to the real and virtual environment.

Generally speaking, the question of whether introducing XR as the sole or complementary method for training is viable or not shall depend on an array of factors: training needs, available resources, health and safety risks, and privacy concerns. Therefore, companies and corporate groups should perform a thorough analysis considering the factors mentioned above to determine whether XR training can yield fruitful outcomes.

For companies to hire employees who meet the standards required in skill acquisition, they need to find new ways to recruit and prepare candidates to join the workforce [26]. Although there is no universally applicable solution, each company

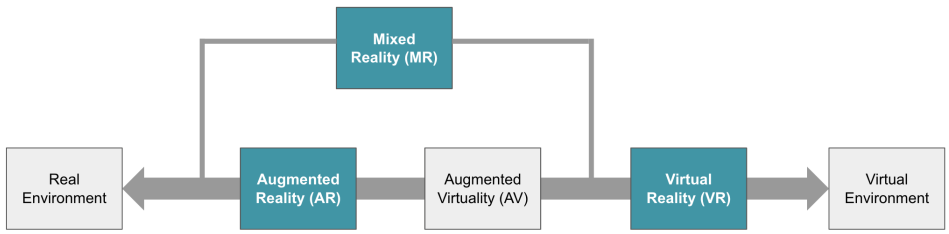

Figure 1.1. Reality–Virtuality continuum adopted from Milgram et al [1].

needs to adjust its various needs to the available resources. Nevertheless, given the constant need to address the recurring complexities of modern manufacturing, it is apparent that building consistent worker training programs is of crucial importance in modern manufacturing organizations [27]. Furthermore, contemporary technologies (XR, sensors, robots) in manufacturing have redefined the boundaries of safety and retention improvement, production optimization, and speed/cost of training processes. Hence, employees can exploit XR features as a powerful and compelling training tool to become familiarized with the demanding real-world working conditions.

As mentioned by Fast-Berglund et al. [28], the ability to blend and exploit the assets of digital/cyber/virtual and physical worlds can produce vital savings of time in various areas of manufacturing (design, logistics, maintenance). Thus, contemporary technologies like XR could act as the missing link accomplishing this bridge, but at the same time, can introduce new features, such as increasing time-room flexibility.

1.2 Terms and Definition

This dissertation is entirely based on immersive environments. Immersive environments are collectively termed Extended Reality (XR). XR includes the following technologies.

- VR - Virtual Reality

- AR - Augmented Reality
- AR - Mixed Reality

Memory and how training can impact and improve the user's memory is extensively discussed. The following two types of memory are considered. (Chapter 5)

- Episodic Memory - Long Term Memory
- Working Memory - Short Term Memory

In this dissertation, the following two tasks were developed to target the episodic and working memory:

- **Picture Sequence Task:** This task was modified to a Toy Assembly Task for Episodic Memory (Chapter 7,8,9)
- **Object Sorting Task:** This task was modified to a Toy Sorting Task for Working Memory (Chapter 7,8,9)

This dissertation presents the designed and implemented systems based on the following frameworks:

- vIS - Vocational Immersive Storytelling Framework
- vIIS - Vocational Interactive Immersive Storytelling Framework
- vIIIS - Vocational Intelligent Interactive Immersive Storytelling Framework
- VISTAS - Vocational Immersive Storytelling Training and Support Framework

1.3 Dissertation Outline

This dissertation consists of 11 chapters that are grouped into five parts. 7 Research Questions (RQ) are also addressed.

1.3.1 Part I: Background

The Background part of this dissertation provides an overview of the motivation behind this research. It also provides an overview of the state-of-the-art art training systems, immersive technologies and introduces related was previously published in this area.

<u>Chapter 1 - Introduction:</u> This chapter gives an overview of the context, introduces the problem and motivation behind researching this domain. Training and assessment of a new worker is the most vital part of any vocational industry. The landscape of jobs and work is changing rapidly, thanks to the emerging new technology and the advancement of knowledge in the scientific fields. This technological and scientific revolution presents an opportunity to create new industries and occupations, enhanced productivity and quality of work-life, and the potential for more people to participate in the workforce. Nevertheless, these come at risk and disadvantage of an increased cost of training and lack of proper training in a few industries.

<u>Chapter 2 - Related Work:</u> This chapter briefly introduces the related disciplines like psychology, arts, and computer science used throughout this dissertation. For providing an overview about related work, I have summarize research projects in the areas of vocational training, industrial tasks, industry-current training methods gaps, technologies used for training & gaps, storytelling and its applications, medi-

ums types, immersive environments such as virtual, augmented and mixed reality for training and also review existing intelligent training systems.

1.3.2 Part II: Investigatory Research

The Investigatory Research part describes user research, requirement gathering, and pilot studies to find potential in the intended research direction. User-Centered Design Process was used for all our studies to train new workers for an assembly task or continuously provide quality support.

Chapter 3 - Investigatory Research: The User-Centered Design process is based on user-centered design principles. In the initial phase, user research was conducted, field visits to industrial sites to find the users' pain points, and gather requirements by conducting interviews with people who have/are learning a new skill. As it is a user-centered design process, every phase of the research is validated by user views and feedbacks. After gather requirements, I designed small pilot studies to test our ideas and formulate our research questions.

Chapter 4 - vIS - Proof of Concept Study: The main objective of this proof of concept study was to understand how stories can be shown in virtual reality environments to teach a new skill. This chapter also answers the following questions: How should the story be told in VR? **(RQ1)**, Amongst 1st person and 3rd person narrative in immersive storytelling, which provides better user engagement? How should the camera movements be designed to ensure maximum user attention while learning in an immersive storytelling environment?, How should the Task instructions be? What is the role of other parameters such as Task Instructions, Dialogues, Length (duration), and Engagement? and Is vIS better than standard task instructions? **(RQ2)**.

1.3.3 Part III: Key Concepts

The Key Concepts part describes the Storyfication framework and Memory that the training systems would impact. Tasks are chosen to impact Episodic and Working memory and improve long-term recall and task performance.

Chapter 5 - Memory: Episodic memory is built of story components. Therefore procedural tasks work best for it. Any continuous task enhances the role of episodic memory. It is also known as long-term memory. Working memory is also known as short-term memory. The information while doing a repetitive task is stored in the working memory. Tasks were selected and designed based on the NIH Toolkit for Cognitive Measures. The NIH Toolbox is a comprehensive set of neuro-behavioral measurements that quickly assess cognitive, emotional, sensory, and motor functions.

Chapter 6 - Storyfication: Storyfication framework defines the process of designing an interactive story suited for training. This can be applied to create any story. It directly impacts episodic and working memory - long-term and short-term memory, respectively, thus increasing engagement, attention, and the retention of information. It is designed by combining the components of a general storytelling graph and gamification features.

1.3.4 Part IV: Evaluation

In the Evaluation part, frameworks are designed, and systems are implemented based on those frameworks to conduct user studies and study the impact of training on human memory and performance.

Chapter 7 - vIIS: The main objective of this proof of concept study was To improve the skills learned in vIS by Interactivity and Storyfication. I designed vIIS - Vocational Interactive Immersive Storytelling System Framework, implemented a system, and conducted a user study to prove our hypothesis 'vIIS performs better than desktop 2D training systems for both working and episodic memory tasks'. This chapter also answers the following research questions, How does interactivity help in the learning process in vIS? **(RQ3)** and Does storyfication enhances user engagement in vIIS? **(RQ4)**

Chapter 8 - vIIIS: The main objective of this proof of concept study was to support the user to perform better at the skills learned in vIIS. I designed vIIIS - Vocational Intelligent Interactive Immersive Storytelling Framework, implemented a system, and conducted a user study to prove our hypothesis 'vIIIS performs better than vIIS for working memory task.' This chapter also provides answers to the following research questions, How can the vIIS system become more intelligent? **(RQ5)** and What are the advantages of vIIIS over vIIS? **(RQ6)**

Chapter 9 - VISTAS: The main objective of this proof of concept study was to support the user to design a training framework to improve episodic and working memory that enables personalized training. I designed VISTAS - Vocational Immersive Storytelling Training and Support Framework, implemented a system, and conducted a user study to prove our hypothesis' VISTAS performs better than vIIS for both working and episodic memory tasks'.

1.3.5 Part V: Results

The Results part contains a summary of the contributions and findings and provides ideas for future work.

Chapter 10 - Guidelines for Designing VISTAS System: Based on the experiences in designing intelligent, interactive, immersive storytelling systems for vocational training and conducting several user studies with different user groups, I have provided general guidelines and recommendations for designing VISTAS systems. **(RQ7)**

Chapter 11 - Conclusion and Future Work: A summary of the contributions of this dissertation is provided in conclusion. Finally, an overview of exciting research topics that are connected to this dissertation is provided.

1.4 Research Contribution

The four primary research objectives of this dissertation are the following::

(1) to facilitate convergent research that employs the joint perspectives, methods, and knowledge of computer science, engineering, learning sciences, research on education and workforce training, and social, behavioral, and economic sciences;
(2) to encourage the development of a research community dedicated to designing intelligent technologies and work organization and modes inspired by their positive impact on individual workers, the work at hand, the way people learn and adapt to

technological change, creative and supportive workplaces (including remote locations, homes, classrooms, or virtual spaces), and benefits for social, economic, and environmental systems at different scales;
(3) to promote a deeper fundamental understanding of the interdependent human-technology partnership to advance societal needs by advancing the design of intelligent work technologies that operate in harmony with human workers, including consideration of how adults learn the new skills needed to interact with these technologies in the workplace, and by enabling broad workforce participation, including improving accessibility for those challenged by physical or cognitive impairment;
(4) to understand, anticipate, and explore ways of mitigating potential risks arising from future work at the human-technology frontier. Ultimately, this research advances our understanding of how technology and people interact, distribute tasks, cooperate, and complement each other in different specific work contexts of significant societal importance. It advances the knowledge base related to worker education and training and formal and informal learning to enable all potential workers to adapt to changing work environments. Finally, it advances our understanding of the links between the future of work at the human-technology frontier and the surrounding society, including the intended potential of new technologies and the unintended consequences for workers and the well-being of society.

This dissertation makes several contributions to the field of Human-Computer Interaction (HCI) with a focus on training technologies:

- Identified and described the requirements for future vocational training systems at the workplace.
- Discussed types of tasks for workplace training and their selection process to impact episodic and working memory.
- Provided a Storyfication model to design stories for interactive training.

- Describe the implementation of a VISTAS Framework.
- Evaluate the implementation and identify future research areas.
- Analyzed and described the qualitative and quantitative impact of the storyfication, intelligent adaptive training systems on working and episodic memory, and work performance.
- Conducted research and designed systems to unify the field of arts (storytelling), computer science (immersive technologies and Artificial intelligence), and psychology (episodic and working memory).

CHAPTER 2

RELATED WORK

This chapter is partly based on the following publications

- *Doolani, Sanika, Callen Wessels, Varun Kanal, Christos Sevastopoulos, Ashish Jaiswal, Harish Nambiappan, and Fillia Makedon. "A Review of Extended Reality (XR) Technologies for Manufacturing Training." Technologies 8, no. 4 (2020): 77.*
- *Gupta, Sanika, Luke Owens, Konstantinos Tsiakas, and Fillia Makedon. "vIIS: a vocational interactive, immersive storytelling framework for skill training and performance assessment." In Proceedings of the 12th ACM International Conference on PErvasive Technologies Related to Assistive Environments, pp. 411-415. 2019.*

2.1 Related Discipline

Learning a new skill and memory are closely related, and immersive environments are proving better training system [29]. Learning is the acquisition of knowledge, skill, or ability, while memory is the expression of what is acquired [30]. Memory is a human's ability to encode, store, retain, recall information gained during past experiences. It is an intellectually superior cognitive process that defines the temporal dimension of the information stored in our brain. Doing any vocation is heavily reliant on memory. Although memory and learning are related concepts, they should not be confused with learning.

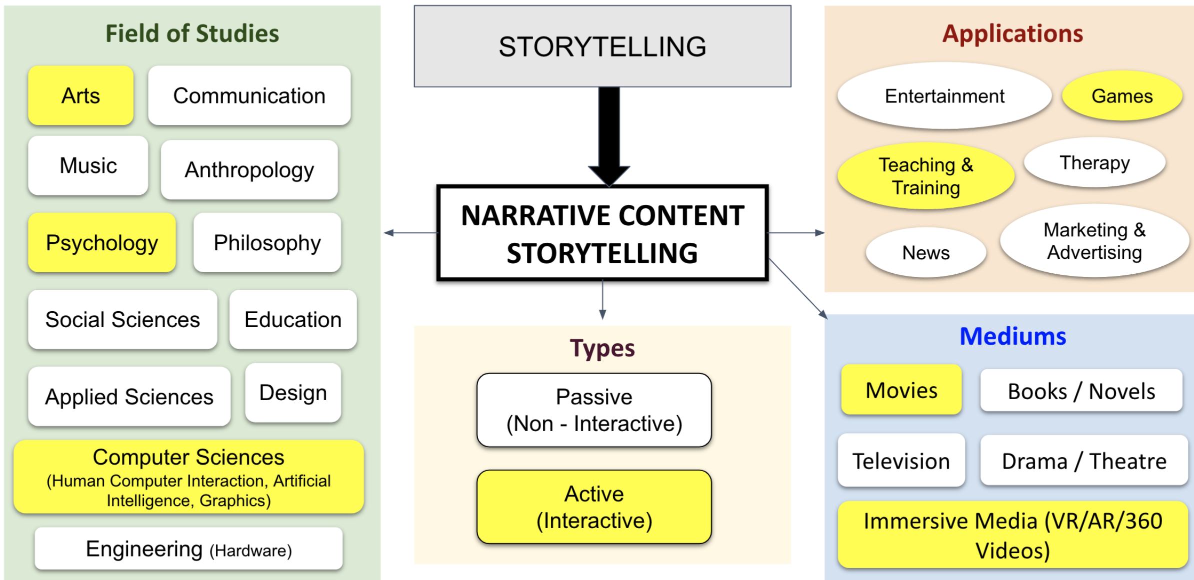

Figure 2.1. Literature Review of Storytelling and Related Disciplines for Training.

To make this work more accessible to readers from various disciplines, I have briefly outlined relevant concepts for designing and developing the VISTAS Framework. Figure 2.1 describes the extent of literature review done for the research to get an overview of the state-of-the-art concepts and technologies, current research, problems, and opportunities. The areas that are selected for this research are highlighted in the Figure 2.1 and are the following:

Computer Science:

- Human-Computer Interaction (HCI)
- Immersive eXtended Reality (XR) technologies
- Augmented reality (AR)
- Virtual reality (VR)
- User-Centered software design
- User experience design (UX)
- Natural interaction (NI)

- Reinforcement Learning (RL)
- Artificial intelligence (AI)

Arts:

- Storytelling
- Gamification
- Storyfication
- Story design
- Story-boarding
- Avatars
- Education
- Narrative Content Storytelling (NCS). The types
- of NCS are active and passive. I chose actively to have interactivity in our training systems. The applications area that inspired our research is from games and teaching/training. Mediums of movies and immersive media are where I wanted to realize my research vision and create our training systems.

Psychology and Ethics:

- Memory
- Cognitive workloads
- Flow and motivation
- Ethical issues
- Cognitive task selection and design

Although these disciplines partly overlap and finally converge in the research topic presented here, they are vast research areas.

2.2 Vocational Training in the Workplace

There have been many studies regarding the inadequacies and difficulties in vocational training. Billet et al. [31] discusses training in the workplace wherein the training benefits the student by providing authentic activities, engaging tasks, and access to experts and other workers. However, there are also many limitations of workplace training, including undesirable knowledge, the reluctance of experts, and knowledge which is opaque [31]. Smith et al. explained that while many students prefer 'on-the-job' training, many workplaces are not equipped to provide the training necessary to facilitate readiness [32]. Other works include language acquisition [23] which focused more on learning a second language using VR. Bruijn et al. assessed various vocational courses in the Netherlands. They found that, in a survey of course coordinators, more robust methods of education were "strong(ly) desired" and that students did not feel they were gaining necessary experience [33]. To improve vocational training while still maintaining the on-the-job experience, our *vIS* system (Chapter 4) puts the trainee in a workplace environment that is controlled, engaging, and has many of the benefits of real-world workplace training like having authentic activities, engaging tasks, and context-based experience. The ability to script the training sequence eliminates the risk of undesirable or opaque knowledge and does not rely on workplace employees' willingness to teach.

2.2.1 Industry tasks

The types of Work Factory Workers do are manufacturing, inventory management, and delivery management.

2.2.2 Factory Worker Duties and Responsibilities

Factory workers' duties and responsibilities are determined by the kind of company for which they work. Based on job listings, a factory worker's duties typically involve were analyzed:

- *Operating machinery:* Factory workers operate machinery, feeding products into the production line, possibly a conveyor line, such as in a canning factory. They monitor the machines, raise any issues with their manager, and control and adjust machine settings, such as the speed.
- *Sorting and packing products:* Once the products have been produced, factory workers sort and pack them, loading them into crates ready for dispatch.
- *Cleaning and maintaining work areas:* Factory workers maintain a clean workspace to uphold health and safety compliance and make sure that the machines are operating correctly. This is especially important in food preparation environments.
- *Quality control:* Factory workers have an in-depth knowledge of the products and materials they are working with, so they notice if a product does not meet specific standards. They check the output to ensure that all products are the same, keeping records of any defective items.
- *Following health and safety procedures:* Health and safety procedures are critical in a factory setting, as accidents can occur quickly if these processes are not followed. Factory workers are responsible for following these systems to ensure their safety and the safety of their team. In addition, they inform their manager of safety hazards.
- *Factory Worker Skills and Qualifications:* Factory workers have good practical skills and can work quickly and methodically. Typically, companies require a

high school diploma and previous experience working in a similar role, as well as the following:

- *Teamwork* – factory workers work with others to ensure efficiency in the workplace
- *Listening skills* – factory workers need to understand how to use machinery properly and safely to prevent accidents and ensure all tasks are completed accurately
- *Ability to follow instructions* – line managers assign tasks and responsibilities, which vary depending on the products being manufactured; factory workers should be able to follow instructions competently
- *Methodical approach* – production lines follow a set process, so factory workers need a methodical approach to ensure all tasks are completed in the correct order for a smooth-running production line
- *Concentration* – factory workers often perform the same tasks repeatedly, so a good level of concentration when carrying out these tasks is important for quality control purposes. This role is often fast-paced, so being able to maintain focus at all times is beneficial
- *Physical stamina* – some factory workers stand for long periods, sometimes entire shifts, and lift packages or materials. Physical stamina and a good level of fitness are important.

2.3 Storytelling-based Training

Storytelling has been linked to increased memory retention [34][35]. Sarica and Usluel studied grade school students over 14 weeks to determine if Digital Story-

Telling (DST) affected writing and visual memory capacity[34]. They concluded, after significant results, that DST increased the children's cognitive capabilities in a shorter amount of time than other traditional methods. Gallets et al. presented evidence supporting this as well[35]. Groups of children presented information that was told interestingly by a storyteller comprehended and remembered the material easier than if they were read to. He concluded that it is likely due to the engagement of the children that allows them to retain and understand the content. Storytelling has also made its way to vocational training and has had positive results. Andrews et al. provided an overview of various storytelling methods and their use in professional instruction[36]. They proposed that the brain's pattern recognition is the primary reason that storytelling-based instruction is effective. Magerko et al. proposed a way to create story-based training by analyzing the trainee's current skill set and experience through the Interactive Storytelling Architecture for Training (ISAT)[37]. Placing emphasis on the skills that need the most work and creating an engaging environment, they argued the training process would take less time [37]. Gandelman and Santoro proposed the use of group storytelling as a replacement for traditional training methods due to cost, time, and content restrictions and offered a technique for its design [38]. Ladeira et al. [39] created a series of videos to teach bed-making and vacuuming skills to domestic workers in India. They found that a high motivational narrative and a strong, compelling action, a story hook, were key in improving the learning outcome. As described in later sections, I describe how I build upon their work and construct a fictional narrative for vocational training.

2.3.1 Storytelling for Education and Learning

Storytelling is the most straightforward way of communication. It predated writing and was used to share ideas, learn and communicate with others. To date, storytelling is proven as the best way to teach and is widely and successfully used in the education sector. Extensive research is also done on how storytelling is useful in fields such as Language learning [40], Teaching [41], Means of Communication [42], Marketing and customer experience [43], PR strategy [44], retail sales [45], Children [46], and also used by socially assistive robots for storytelling, Gamification in storytelling, Journalism, Social movements, Online campaigns, Dementia, Collaborative storytelling, Video games, Visualization, Stress, other emotional and psychiatric uses.

Training and assessment exercises inside the college condition are still often limited by classroom dividers and the absence of authenticity[47]. Addresses these issues by immersing the students in a virtual environment and gets them acquainted with a storyline. In addition, gamification components are utilized to expand the commitment with nature and spotlight consideration on the assignments at hand, including students' interest and experience to expand self-coordinated learning.

2.3.2 Digital Storytelling

Digital storytelling is a term used when digital tools and technologies are used to tell a story. They are much more engaging and informative. Digital Storytelling has been evolved dramatically since technology advancement and easy access to digital content from cable networks and the internet. [25] tells the use of Digital Storytelling in the classroom and education. With the rise of emerging technology, immersive mediums such as VR/AR are being started to use for more engaging storytelling.

2.3.3 Interactive Storytelling

Interactive storytelling (otherwise called Interactive dramatization) is a type of advanced excitement in which the storyline is not foreordained. The writer makes the setting, characters, and circumstance the account must address; however, the client (likewise per user or player) encounters a novel story dependent on their associations with the story world. All intelligent narrating frameworks must make utilization of human-made reasoning (Artificial Intelligence - AI) somewhat. The engineering of an intuitive narrating program incorporates a dramatization supervisor, client model, and operator model to control, individually, parts of story generation, player uniqueness, and character learning and conduct. Together, these frameworks produce characters that demonstrate "human" change the world continuously responses to the player, and guarantee that new story occasions unfurl conceivably.

Interactive storytelling in a blended reality condition combines advanced digital and physical data. It, as a rule, utilizes an increase of this present Reality and physically-based connection to make an immersive experience that relates to the emotional storyline of the intelligent account impacted by the activities of the client. Immersion is a pivotal part of such an establishment. It can be impacted by various factors, for example, video, sounds, communication, and, at last, the density of every single joined improvement in the environment. [48]

2.4 Immersive Environments for Training

Virtual Reality has been utilized throughout the world to increase access to vocational training [49][50]. Akshay et al. [49]presented the Mobile Vocational Education (MoVE) units designed to provide vocational training to rural and tribal populations of India. The system provides various levels of training for multiple vocations. Due to the software's portability, mobility, and low cost can provide training to a larger population than through traditional means. Similarly, Muller and Ferreira et al. introduced the Mechatronics: Access to Remote and Virtual E-Learning (MARVEL) product, focusing on expanding access to mechatronics vocational training[50].

MARVEL uses real and virtual environments and strives to create social contexts to provide a better learning experience. Oguz et al. argue that in order to improve vocational training education in Nigeria, access to computers and Information and Communication Technology (ICT) is vital[51]. While the cost associated with the development of Virtual Reality based training software could be expensive, the benefits of an increased education of a larger workforce far outweigh the cost of the associated technology. Our VR system would provide access similarly: VR headsets loaded with training scenarios can be repeated by many trainees to eventually provide a low-cost learning environment.

Carlson et al. used a burr puzzle to test VR's effect on skill acquisition[52]. They found that by having color cues in virtual reality and the same colors in the physical world, the long-term skill retention was higher than learning the burr puzzle in a purely physical environment. Jou and Wang also found success in training students within the Virtual Reality Learning Environment (VRLE)[53]. They emphasize the importance of practical training and highlight the perks of the VRLE's ability to provide this training. VR has also been used to implement storytelling. Mollet and Arnaldi discuss the GVT platform, a maintenance virtual reality training program that uses storytelling to train employees how to develop certain skills[54]. The GVT platform is meant to be used as a trainer's tool, not as a replacement for an expert. They focus on creating scenarios based on constraints and goals rather than a sequence of linear events. Lugrin et al. discuss storytelling in VR from an entertainment point of view[55]. They developed an immersive interactive narrative that the user participates in. The participants showed a willingness to engage in interactions and were active within the narrative in a productive way.

Wood and Reiners highlight the difficulties of traditional learning methods and the benefits of using virtual environments with storytelling elements[47]. They use the project *nDiVE* to show how storytelling and gamification can increase engagement and self-directed learning. Repeated use of the same virtual scenario can show a trainee various benefits, trade-offs, or consequences of their actions. Gelsomini et al. [56] evaluated the use of storytelling and VR to provide therapies for children with Intellectual and Development disorders and found that the system was beneficial in triggering a learning process and helped them stay focused in performing a task. Here, the storytelling content positively affected learning outcomes inside a VR environment on such delicate users. Our vIS system utilizes storytelling inside of a virtual workplace to provide a cost-effective and controlled learning environment while still providing the on-the-job context desired. It combines many aspects of the systems discussed here to provide a complete learning experience focused on user engagement and knowledge retention. Rather than a tool, our system uses a complete scenario to provide instruction, demonstration, and experience without the need for an expert to be present.

Immersive environments are better than traditional methods of language learning [23]. Users remember and retain information for more time and perceive better enjoyment while using an immersive virtual reality system for learning. Immersive environments such as virtual and augmented reality can be used as training platforms. Bailenson et al. discuss two aspects of virtual Reality that contribute to media interactivity by performing two experiments examining each aspect and how they affected the user's learning experience [57]. In the first experiment, the user was able to see an avatar of themselves performing specific tasks in the VR environment. In the second experiment, users were able to see an avatar of themselves and a reflection of themselves and their environment using a virtual mirror. In both experiments, users had better learning outcomes due to the interactive VR environment's added interactivity. DeKanter [58] discusses networked game simulations and their effect on increasing interactivity in learning environments. The author connects current game simulation design with the Learning Pyramid and explains how they similarly drive to connect students and teachers. They also detail past games that have been made and their reception. Kent et al. [59] describe the importance of interactivity and social interactions within a learning environment. They analyze the relationship between interactivity and learning outcomes using quantitative data from multiple learning communities' online discussions. The researchers conclude that that interactivity is a central aspect of social learning. Vocational immersive storytelling system [29] proved the user's ability to retain their training after the gap was nearly equal for immersive and the 2D video-based technique and was considerably higher than the text-based technique.

Pedra et al.[60] examine the effects of adding interactivity to lessons performed on handheld devices. Researchers showed that adding interactivity to a short, five-minute animation of a maintenance procedure increased interest in the activity but did not show any correlation between interactivity and better learning. The interactivity features explored included the ability to rotate and zoom into the 3D animation but did not include any interactive actions with the model itself, such as performing the maintenance action itself. Micallef et al. [61] examine the effects of adding interactivity to students' museum visits. When paired with QR codes around the museum, a mobile application was developed that featured quiz software to facilitate interactivity. Students that used this mobile-based version of the game rather than a paper-based quiz scored higher on a post-assessment. Finally, Domagk et al. [62] introduce a unifying model that attempts to clarify the concept of interactivity itself. Their model utilizes six integrated components: the learning environment, behavioral activities, cognitive and metacognitive activities, motivation and emotion, learner characteristics, and the learner's learning outcomes. The researchers believe that this model could better discuss interactivity by allowing for the decomposition of its integral parts.

Alloway and Alloway [63] discuss the relationship between working memory and academic attainment. The researchers found that children's working memory was a better predictor of their future literacy and numeracy than IQ. They claim that working memory is a dissociable cognitive skill that has important implications for education. Armstrong and Landers [64] describe the recent research into the gamification of web-based training. They offer an overview of the current methods of applying gamification principles in several domains. They also provide a step-by-step process of how to gamify training and offer insight into when to utilize gamification. Landers and Armstrong [65] use the Technology-Enhanced Training Effectiveness Model (TETEM) in the context of gamification. They created two scenarios involving managerial training: one that implements gamification and a control scenario that described a typical powerpoint-based training. The users found that there was support for gamification, but a few individuals thought that gamification led to a less valuable training experience. Landers and Callan [66] describes how and when gamification is appropriate in the context of undergraduate education and employee training. They also analyze a 600-student study on gamification. The researchers state that gamification should only occur after initial learning outcomes and objectives are recorded. They conclude that gamification can improve learning and training by offering social rewards meaningful to the student or trainee by increasing their motivation to complete tasks. Armstrong and Landers [67] analyze what elements of game design are most conducive to learning when utilizing gamification. Their results of analyzing 273 participants showed that while there is more satisfaction gained from gamification, there is no difference in the declarative knowledge gained. They found that gamification has a negative effect on procedural learning, so there is a measurable loss in training effectiveness when gamification is introduced.

To solve the problem of training workers for future jobs and new emerging technology, it is essential to provide more engaging and better learning opportunities. There is a need to facilitate crucial research that combines perspectives, methods, and knowledge of computer science, engineering, learning sciences, research on education and workforce training, and social, behavioral, and economic sciences. There is also a need to design intelligent technologies that can positively impact individual workers, the work at hand, the way people learn and adapt to technological change, creative and supportive workplaces (including remote locations, homes, classrooms, or virtual spaces). Assessment is as vital as training. Testbeds need to address all the factors that can provide general feedback after the training. Lastly, as these new technologies enter future work environments, the need to understand, anticipate, and explore ways of mitigating potential risks. This paper aims to provide a framework that will advance the knowledge base related to worker education and training and formal and informal learning to enable all potential workers to adapt to changing work environments.

2.4.1 Impacts of Immersiveness on training

Bailenson, Jeremy et al. [68] describes the utility of using virtual reality environments to transform social interaction via behavior and context, intending to improve learning in digital environments. They conducted four experiments and demonstrated that teachers with augmented social perception could spread their attention more equally among students than teachers without augmented perception. Conventional ways to deal with learning have regularly centered upon information exchange techniques that have focused on textually-based commitment with students and dialogic strategies for collaboration with mentors as discussed in [69]. The utilization of virtual universes, with text-based, voice-based, and sentiment of 'nearness' normally was considering increasingly complex social associations and planned to learn encounters and pretends, just as empowering student strengthening through expanded intelligence. [70]

Immersion in a digital experience created by the virtual environment involves the suspension of disbelief and the design of immersive learning experiences that creates fake sensory, actionable, and symbolic factors. Sensory immersion replicates digitally the experience of location inside a three-dimensional space; total sensory interfaces utilize either head-mounted displays or immersive virtual reality rooms, stereoscopic sound, and through haptic technologies that apply forces, vibrations, and motions to the user—the ability to touch virtual objects. In addition, interactive media now enable various degrees of sensory immersion [71].

Virtual Reality offers the required crucial characteristics of Immersion, Interaction, user involvement with the environment, and storytelling offers excellent potential in education by making learning more motivating and engaging as discussed in [3]

2.4.2 Use of Interactivity in training

Correspondence can happen between individuals, individuals, machines, individuals, programming, machines, and machines. Regarding human-computer situations, intelligence can have numerous implications, contingent upon whether the setting is operational, mechanical, or down to earth (in which case its investigation includes the HCI and interface configuration fields), instructive, social/communicational, masterful, or recreational. Intuitiveness has been characterized as the capacity of information required by the client while reacting to the PC and the idea of the framework's reaction to the information activity. [72] sees intelligence as the degree to which clients of a medium can impact the structure or substance of the interceded condition. Be that as it may, this definition does not involve any reaction; an extraordinary and significant impact on a domain can be to turn it off, which includes no complimentary activity from the earth, and is commonly not thought about as an intuitive capacity.

Learning through activity: Current reasoning about how learning happens underscores the constructivist approach, which contends that students should effectively "develop" learning by coaxing it out of encounters that have significance and significance to them. Members in a movement develop their insight by testing thoughts and ideas dependent on earlier learning and experience, applying them to another circumstance, and incorporating the new learning with previous scholarly builds, a procedure natural to us from real-world circumstances. The individual consistently builds speculations and subsequently endeavors to create information that must, at last, be sorted out. These perspectives have affected the improvement of intelligent and virtual learning conditions, which appear to tie in well with the "learning by doing" and "hands-on" practices of present-day exhibition halls. Also, since computer-generated reality advances give a broad scope of potential outcomes for this sort of intuitiveness and backing for an active interest in developing the substance, they turn out to be appropriate, incredible media for schools galleries, and edutainment focuses.

Learning through Play: The rapid development and notoriety of amusements have activated expanding enthusiasm among analysts, and various examinations have been completed accordingly. A few hypotheses tie the conceivable learning outcomes given by diversions to inspiration and commitment. Maybe the best known is crafted by Malone [73], which considers diversions as suppliers of characteristic inspirations for learning. The initial four sorts of inborn inspirations (challenge, interest, control, and dream) might be present in any learning circumstance, even those that include just a single individual. The other components of characteristic inspiration (rivalry, participation, and acknowledgment) are arranged as relational inspirations since they depend on the presence of other players. There is a solid association that ties intelligence, commitment, and learning[74]. Together, they can frame the establishment to advance a fruitful augmented simulation condition: an intuitive VR "play space," which permits kids to take part in an imaginative and productive play and accomplish the perfect mix of instructive and recreational esteem[75].

2.5 Training Systems supporting Cognitive Performance

Classic cognitive training tasks train specific cognitive aspects (e.g., processing speed or memory) using guided practice on standardized tasks. Neuropsychological software programs (e.g., NeuroPsychological Training, Colorado Neuropsychological Test) are designed to enhance multiple cognitive domains using various tasks and provide instant performance feedback. They are primarily self-guided, allowing participants to progress through tasks at their own pace. For example, Kreider et al. [76] describe that video games can include electronic or computerized games in which the player manipulates images on a screen to achieve a goal. All cognitive domain-specific tasks are measured in terms of, and are aimed at, improve the cognitive speed of processing, memory, attention, perception, time taken to finish the task, reaction time, executive function, and managing cognitive load in general, which increases engagement and enjoyment during the task.

The cognitive performance and wellness of the worker are essential. In this era of Industry 4.0, when automation has enlarged an individuals' work routine, a higher cognitive level is in demand due to the flexibility and adaptation of tasks. Job characteristics and computer anxiety in the production industry [5] discuss this higher level of cognition needed with high workload, increased work pressure, diminished job control, training, and use of new technologies.

Imran et al. [77] designed a virtual reality application to measure cognitive performance in the presence of various background noises. Specifically, the use of virtual Reality allowed for the real-time naturalization of speech in an office environment. The study was conducted to determine whether reducing speech intelligibility due to frequency-specific insulation between office spaces affected cognitive performance. The authors concluded that VR had no significant impact on the results of the cognitive performance task when compared to an analogous study conducted in a real-world environment. The study showed promising results in achieving generalized predictions of cognitive performance in humans.

Kotranza et al. [78] designed a mixed environment (ME) simulation that trains and evaluates both psychomotor and cognitive skills. The user receives real-time virtual visualization and feedback of their performance in a physical task through multiple sensors in the physical environment. The approach was used in an ME for learning clinical breast exams, and various feedback methods were detailed.

Papakostas et al. [79] propose a vocational tool for cognitive assessment and training (v-CAT). The goal of v-CAT is to provide personalized autonomous training options for each user. The tool uses data gathered from multiple sensors while the user completes various tasks while immersed in a simulated virtual workplace/factory environment to assess the user's physio-cognitive state. The tasks used in the tool utilized virtual Reality, computer vision, and sensors. The results can then be used in conjunction with machine learning, deep learning, and reinforcement learning to prioritize areas of training that are most needed.

Augstein et al. [80] designed a table-top-based system that can be used to enhance cognitive performance in complex tasks. The system was designed to aid in neuro-rehabilitation by eliminating many time-consuming tasks customarily left to professionals. The system uses various modalities for interaction, including touch, tangibles, and a pen to support different patients' variable range of motion. Training sessions are recorded and then analyzed at a later time. The researchers found a high acceptance of the system in the three participants that were chosen.

Sharma et al. [81] use various physiological features such as heart rate and facial features to estimate a person's cognitive performance. The researchers wanted to examine the feasibility of this system in separate, distinct tasks that often require different cognitive processes. For example, a game of Pac-Man, an adaptive assessment task, a code-debugging task, and a gaze-based game are all used to gather features.

Costa et al. [82] present an application utilizing smartwatch hardware that aims to regulate emotions and reduce anxiety to improve cognitive function. The application gives the user haptic feedback, simulating a heartbeat. The researchers gave 72 participants math exams. Half of the participants had watches that simulated a slow heartbeat and the other a fast heartbeat. Results showed that simulating a slow heart rate led to positive cognitive, physiological, and behavioral changes.

CHAPTER 3

INVESTIGATORY RESEARCH

This chapter is partly based on the following publications

- *Abujelala, Maher, Sanika Gupta, and Fillia Makedon. " EvalVR: Evaluation of User Experience of popular Virtual Reality Applications." Proceedings of the IWISC 2018: 3rd International Workshop on Interactive and Spatial Computing*
- *Doolani, Sanika, Callen Wessels, Varun Kanal, Christos Sevastopoulos, Ashish Jaiswal, Harish Nambiappan, and Fillia Makedon. "A Review of Extended Reality (XR) Technologies for Manufacturing Training." Technologies 8, no. 4 (2020): 77.*

3.1 User-centered Design Process

User-centered design is an iterative design process in which designers focus on the users, and their needs in each phase of the design process [83]. User-Centered Design (UCD) is a set of processes that focuses on the needs, desires, and limitations of users of the product being built. In UCD, the design problem is solved iteratively, validating the product design with user feedback. It is essential to learn how a user thinks. So the target audience for whom the product is being built is interviewed, and user studies, notes, specification documents, and workflow documents are made. From this, the ideation process takes place, after which early prototypes are formed and constantly user-tested. After this step, designers and developers build user-centered

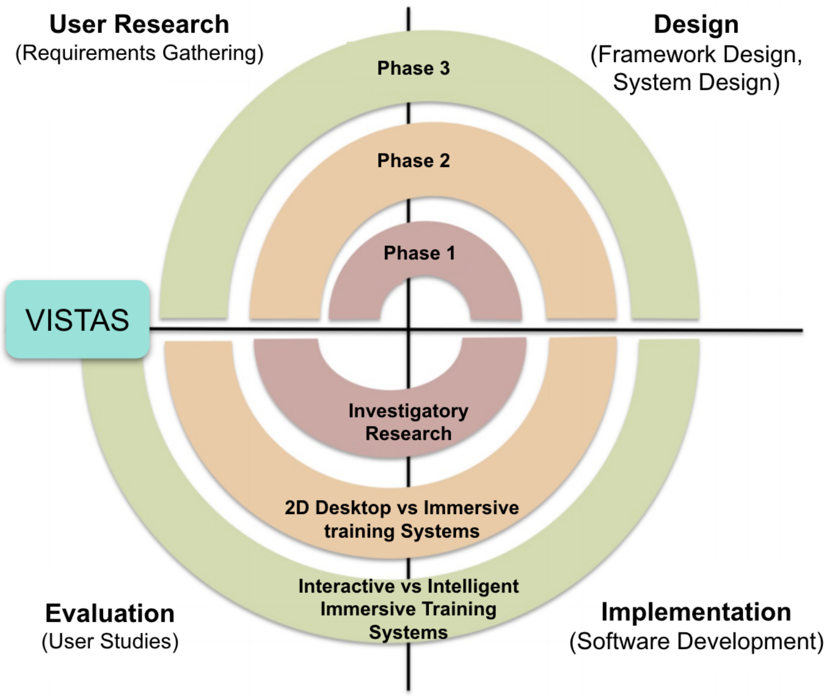

Figure 3.1. User Centered Design (UCD) Process Phases.

solutions on which final user testing is conducted to ensure usability. Usability is a measure of the interactive user experience associated with a user interface. UCD offers a more efficient, satisfying, and user-friendly experience for the user. By understanding the human emotions, motivations, and beliefs surrounding a task, a user interface can be designed to accommodate and support user behaviors so that users would experience as natural and satisfying. In UCD, the projects are based upon an explicit understanding of the users, tasks, and environments. First, to span the entire user experience, the users must be involved in the evaluation process.

The research approach used in this dissertation has three phases (iterations) and uses a bottom-up approach. Each iteration follows the user-centered design process consisting of the following steps: First, requirements were gathered through field research and interviews with different user groups and experts from the industry according to which a design was created. Secondly, the vocational training system was implemented based on the initial design to use the design aspects that needed to be studied rapidly. Lastly, from the identified requirements in the first step, I formulated hypotheses and subsequently designed frameworks of my proposed systems. To scientifically evaluate the correctness of the formulated hypotheses, empirical user studies were conducted using the prototypical implementation of the design based on the frameworks and testing different aspects of the design with users. Considering the results of the user studies of the previous phase, I afterward repeated the user-centered design process and address a new aspect of the vocational training system. Within the scope of this dissertation, I considered dividing the user-centered design process into three phases, as explained in Figure 3.1.

A graphical representation of the three phases of the UCD approach is depicted in Figure 3.1. Every phase has four sections consisting of User Research, Design, Implementation, and Evaluation. Information collected in one section helps make design decisions in the next section. User Research comprises requirement gathering through qualitative and quantitative methods like user interviews and surveys, respectively. Research questions are also formulated in this section. In the design section, user data collected in the research phase helps create a system design, and in our case, I designed frameworks. Phase 1 user research consists of factory visits and user interviews. Based on these, I designed, implemented systems, and conducted user studies to formulate research questions to investigate further in this research direction (Chapter 3). In Phase 2 (Chapter 7), I designed a framework, implemented systems to find whether interactive, immersive storytelling systems are better than 2D desktop-based training systems. In Phase 3, I furthered our research to investigate how better intelligent, adaptive, interactive, immersive storytelling systems perform compared to the interactive, immersive storytelling systems (Chapter 8). The final result of our research was the creation of the VISTAS framework (Chapter 9,10).

3.2 Requirements Gathering - User Research

To gather user requirements, it was necessary to interact with the user, understand their workplace and their pain points to uncover opportunities and research problems. I conducted field research by visiting the manufacturing industry, assembly factories, and facilities where workers are trained and work repetitively on a job. I visited **Arlington Waste Management Facility Foxconn Centre and General Motors Assembly factory** (Figure 3.2) to investigate first had how the workers work in an actual factory setting. The goal was to understand their challenges and pain points and see the current vocational training methods. I investigated their challenges and pain points, and I was introduced to the current methods of vocational training.

- Types of Work Factory Workers do
  1. Manufacturing
  2. Inventory Management
  3. Delivery management
  4. Operating machinery
  5. Sorting and packing products
  6. Cleaning and maintaining work areas
  7. Quality control
  8. Following health and safety procedures
- Factory Worker Skills and Qualifications
  1. Teamwork

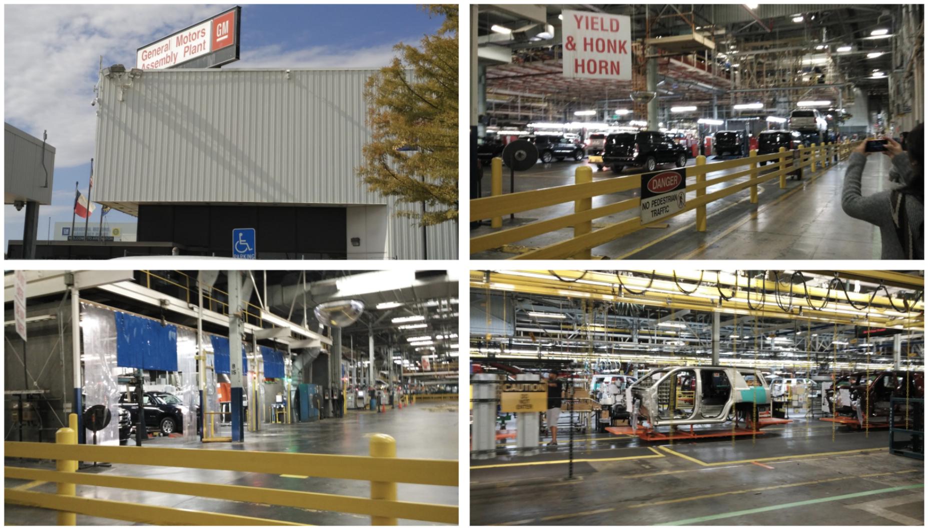

Figure 3.2. General Motors Assembly Factory - Arlington.

2. Listening skills
3. Ability to follow instructions
4. Methodical approach
5. Concentration
6. Physical stamina

The answers to the following questions were found out by conducting interviews with people who have/are learning a new skill during the field. Like it a UCD process, every phase of the research is validated by user views and feedbacks. The questions to evaluate the UCD process are the following:

- How do workers learn a new workplace skill?
- How fast do they learn?
- How existing training system work?
- How can VR improve the learning experience?
- What are the assumptions?
- Who are the audience/user/stakeholders of the system?

Arlington Waste Management Facility: In this waster management facilities, workers are trained to sort plastic from the conveyor belt filled with all kinds of trash. They had an automated system to sort iron trash by having magnetic machinery over their conveyor belt. I spoke to the factory manager and asked questions on how the workers are trained? How much time do they have to sort the plastic trash? What are the shortcomings of the current training method? I learned that the current training method is by employing a senior worker to train the new worker. They were struggling with high workers leaving the job because it takes a lot of time and resources to train a new worker. Therefore, replacing or finding a new worker often is challenging.

Foxconn Centre: Foxconn center is an Apple phone assembly plant where all the versions of Apple assembled, inspected, and packaged for delivery to the Apple Stores. The workers follow a strict schedule of assembling and have a fixed routine of doing their jobs and taking a break. There was a series of stations. Every worker was responsible for a particular job on the Apple mobile phone and then passed the phone to the next station for the following parts to be assembled. In this way, a series of workers completed the assembly of a mobile phone. Their worker stations had fixed places to keep assembly parts. I interviewed the center manager and learned about their training process. They are given training based on their expertise and skill level through video instructions and in-person assistance. During this field research, the pain point identified was that workers have high burnout during the training phase due to an immense amount of information. On the other hand, they were positive and enthusiastic about a more entertaining way of training.

General Motors Assembly Plant: This manufacturing plant manufactured SUVs and trucks. They had different sections for assembly, paint factory, and inspection. There is a different conveyor belt for every piece of car part in the assembly sec-

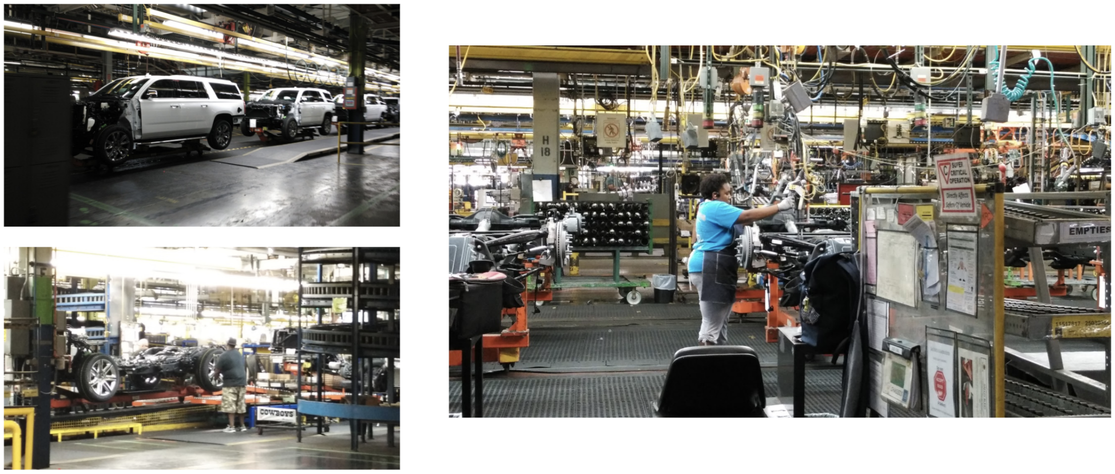

Figure 3.3. General Motors factory workers working on car assembly line.

tions that need to be assembled. The workers are on a tight and timely schedule to assemble a car part. For example, in Figure 3.3 the worker needs to assemble the car engine parts within six seconds; otherwise, the current car would pass on to the next station, and the next car on the conveyor belt would arrive at her station. If the timing is not correct, the worker can get hurt. The training of such an assembly plant is very precise and needs certification. When the floor manager was interviewed, he informed that every worker who spends six months of training needs to complete a certification. When they arrive on the floor, they are assigned a senior worker to oversee their initial days. They were also working on virtual reality training systems, but it was still in the research phase. This showed promise to our research direction.

3.3 EvalVR Project

Virtual Reality is a technology that enables people to experience the world beyond its Reality, is proving to be beneficial in many different areas such as training, entertainment, healthcare. However, if this technology needs to serve humankind on such a large scale, it is crucial to understand the experience of its users and tackle their needs.

Motivation: The main goal of this project is to investigate four commercially popular VR applications of different genres to find limitations and pain points of this technology and discover new research questions.

3.3.1 Background

Virtual Reality technology has multiple uses in engineering, arts, business, entertainment, gaming, therapy, training, robotics, healthcare, or sometimes a combination of these fields [84].As this technology has such a wide range of applications, it is critical to evaluate the user's experience continuously as the technology progresses to evolve. [85] presents a survey on presence in VR discusses how important it is to find the key contributing factors for development of VR applications. To completely understand the impact of VR applications, [86] discusses the benefits of studies outside the laboratory. A bunch of qualitative studies were conducted by Berg et al. [87].To better understand the current state of VR applications.We see a fast growth of head-mounted displays in the commercial market, making this technology accessible to the masses. To find out what areas of virtual Reality can be further improved, I needed to investigate the user's experience of current VR applications. This research study is being done to find out the users' experience when they use a VR system. The goal was finding out how users interact with a VR system, their problems, what they find enjoyable or challenging, and understand their behavior. In contrast, they interact with the virtual environment.

3.3.2 Research Design

Four different genres of VR applications were selected: a 360- degree video (Google Earth [88], Figure 3.4), a VR task training application (Job Simulator Office Worker [89], Figure 3.5), a VR game (Archery first-person shooting game [90], Figure 3.6), and a VR experience (Google Tilt Brush [91], Figure 3.7). These applications were selected because of their popularity in the commercial masses. For each participant, the study took 45-60 minutes. Before the study began, each participant spent five minutes in a VR environment (The Lab - Vesper Peak [8]) to learn the controls and navigation in the VR environment with the supervision and guidance of an investigator. After getting comfortable using VR, the participants used each VR application independently for five minutes. Each participant used all four VR applications. The order in which the participants used those four games was random. This randomness was chosen to ensure the feedback is not dependent on the previous VR experience and prevent data collection from any such dependencies. The study was designed to gather immediate feedback from the participants after using each VR application. This ensured they gave the right feedback corresponding to the VR application just used. After using all the four VR applications and filling a questionnaire for each of them, the participants were given a final questionnaire. A range of general questions was asked in the final questionnaire, such as age, demographics, and previous VR experience. Other questions based on overall VR experience like fatigue, dizziness, pain, discomfort were asked. For this study, HTC Vive was used as the VR system.

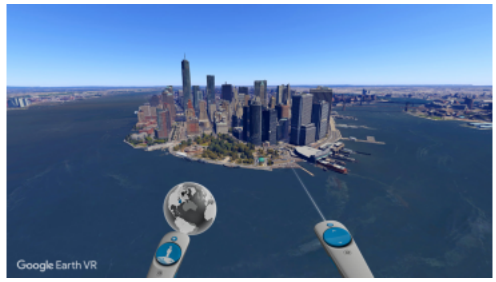

Figure 3.4. Google Earth: a 360- degree video.

3.3.2.1 Virtual Reality Tasks

1. *Google Earth VR* is an immersive experience of navigating the earth using VR controls. The participants were asked to pick any city of their choice and take a tour for five minutes.
2. *Job Simulator Office Worker* is a VR simulation of an office consisting of many subtasks. These subtasks include pouring coffee, waking up the computer to look busy, hiring, using spreadsheets, and using a vending machine.
3. *Arcade Shooting* is a first-person bow and arrow shooting game. The main goal in this task is to place the arrow in the bow, aim at the object (most of them are moving objects), and pull/release the arrow.
4. *Tilt Brush* is a room-scale 3D painting virtual reality application developed and published by Google. The participants have the freedom to select different colors and brushes to design/paint a 3D object.

Four different genres of VR applications were selected. For each participant, the study took 45-60 minutes. Before the study began, each participant spent five minutes in a VR environment to learn the controls and navigation in the VR environment with supervision and guidance. After getting comfortable using VR, the participants used each VR application independently for five minutes. The order in which the participants used those four games was random. This randomness was chosen to

Figure 3.5. Job Simulator Office Worker VR Game.

Figure 3.6. Archery first person VR shooting game.

ensure the feedback is not dependent on the previous VR experience and prevent data collection from any such dependencies. The study was designed in a way to gather immediate feedback from the participants after using each VR application.

Figure 3.7. Google Tilt Brush VR Experience.

3.3.3 User Study

In the user study, 13 participants (5 females, eight males) between the age of 18 and 34 years tried the four VR tasks (Figure 3.8). Most of them (69.2%) reported prior VR experience, but only 27.3% of them identified themselves as VR experts. As mentioned before, the participants completed a questionnaire after each task, and they answered another questionnaire with demographic and overall experience questions at the end of the experiment. The majority of the participants (61.5%) wear glasses in general, and none of them reported any readability issue while using the VR headset without glasses. Similarly, most of them did not feel dizziness (100%), tiredness (92.3%), nor pain (76.9%). On the other hand, 38.5% of them reported some difficulty in learning how to use the controllers. Many of them stated that figuring out how to use the controllers to control the environment and dealing with the system's wires and movement limitations were the most challenging aspect of this VR project. That might be because most of the participants are less frequent gamers as 69.2% of them spend between 0-2 hours per week on video games. Next, I discussed the questionnaire after each of the tasks separately and then compare participant's feedback on three of the tasks (i.e., Archery, Job Simulator, and Tilt Brush).

Google Earth Task: 84.6% of the participants found this VR task very responsive, and 61.5% of them found it very enjoyable. However, with that mentioned, 23.1% of the participants found the task disorienting, resulting from the VR design, as participants can move from a place to another flying (virtually). According to the participants, the problematic aspect of this task is to understand the instructions on how to use the controllers to navigate, and the favorite aspect was that they could easily visit see new places and places they admire.

Archery Task: 61.5% of the participants reported some archery experience (real and game experience), so most of them know at least the very basics of archery.

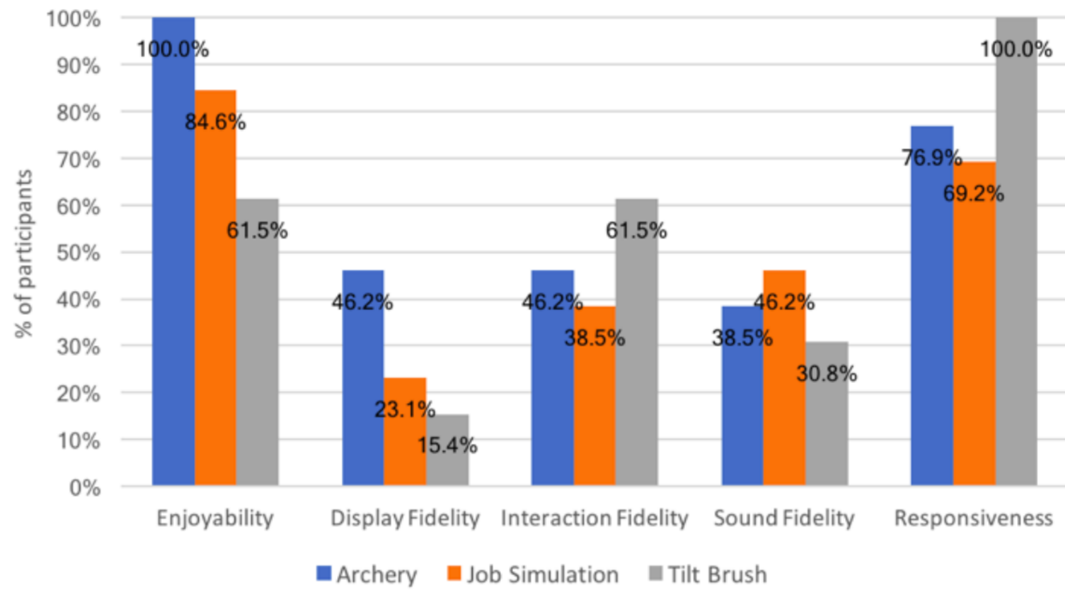

Figure 3.8. EvalVR User Study data compares between participants' feedback on the enjoyability, display fidelity, interaction fidelity, sound fidelity and responsiveness of the VR task.

Accordingly, 84.6 of the participants found the game easy, and those who reported difficulty stated that aiming and unfamiliarity with the controllers were the problematic aspects of the task.

Job Simulator: 46.2% of the participants reported that it was not very easy to follow the instructions. Many of them stated that the lack of proper instructions was the most challenging part of this task. The instructions are available on display in a VR environment, and some of the participants did not notice those instructions.

Tilt Brush: Most participants (76.9%) found it easy to navigate the selection menu. However, some reported that it was slightly difficult to change between the different color options and place them using the controllers. Figure 2 shows how many participants found three of the tasks very enjoyable, looking realistic (display fidelity), feeling realistic (interaction fidelity), sounding realistic (sound fidelity), and responsive.

3.3.4 Learnings

We investigated four commercially popular VR applications (Google Earth VR, Job Simulator, Archery Game, and Tilt Brush). I found out that problems such as dizziness readability issues were absent; on the other hand, the participants still have some issues with unnatural interaction using the default handheld controllers. In addition, they had difficulty adjusting to new environments as the controls and navigation in each changed.

In this project, I conducted user studies to gain insights into user experiences. In addition, I investigated four commercially popular VR applications (Google Earth VR, Job Simulator, Archery Game, and Tilt Brush).

Our findings conclusively showed how current popular VR applications are perceived by users and can still be improved. I found out that problems such as dizziness readability issues were absent; on the other hand, the participants still have some issues with unnatural interaction using the default handheld controllers. They had difficulty in adjusting to new environments as the controls and navigation in each changed.

3.4 Lego Project

After finding the pain points, opportunities, and potential of Virtual Reality, I wanted to find the task instruction design, assembly of products, and potential of storytelling for such an assembly project. So I decided to do a lego assembly project inspired by the research study done by RJ Adams et al. [92] and [93]. It is essential to understand the experience of its users, how they assembled lego parts, how storytelling training was perceived and how well they assembled in a collaborative study.

Motivation: The main goal of this project is to conduct a pilot study with Lego to study how users do assembly work and find pain points design opportunities.

3.4.1 User Study

We conducted an in-lab pilot study with 3-5 participants for each study (Figure 3.10). A lego assembly of helicopter and police station has used this project (Figure 3.9). The participants were grouped into randomly assigned pairs another participant for collaborative assembly tasks. Each participant was given an overview of the study. Participants first constructed each part of the helicopter in order to familiarize themselves with task materials. Pairs then performed their tasks by building helicopter and police stations in each condition. Each participant or a pair of participants was assigned to complete one of these studies. After completing the study, every participant was interviewed. The participants first learned how to assemble the lego toy either by an instruction paper-based book, a video instruction, or a story. The story was created based on the chunking method of remembering sequential information [94]. A story was designed to engage the participant in building a helicopter and police station to save the world. The conditions were randomized and were not assigned to a specific assembly task. Different sets of studies were designed.

- Build Helicopter Lego set using book instructions
- Build Helicopter Lego set using video instructions
- Build Helicopter Lego with Music
- Storytelling – character – build Lego to save the world
- 2 participants building Helicopter Lego using book instructions
- 2 participants building Helicopter Lego using video instructions
- Storytelling - 2 people - Build Lego to save the world

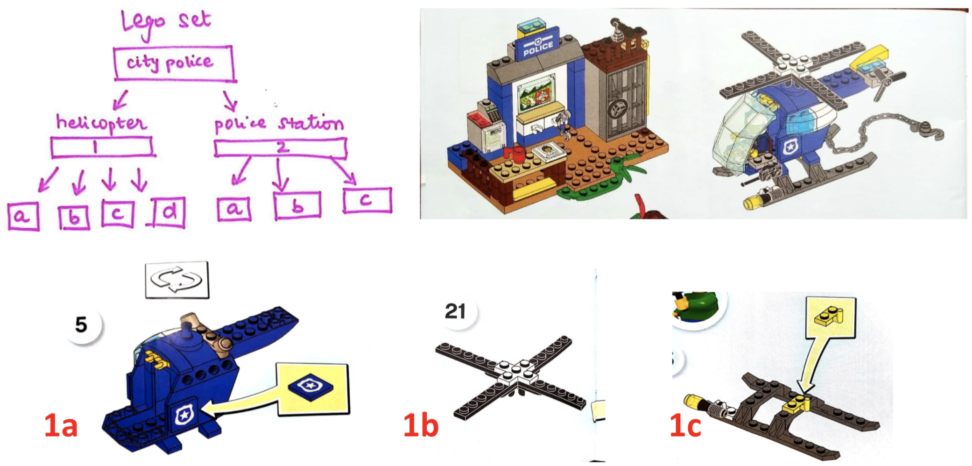

Figure 3.9. Helicopter and Police Station Lego, Chunking method for Storytelling in Lego Project.

3.4.2 Learnings

After conducting multiple studies, I conducted participant interviews to learn more about their experience. The top three learnings of this study were There is a need for more research on story design and storytelling frameworks for immersive platforms. The task needs to be together, and the story should be around it. There is a high potential of storytelling-based training systems as the participants had a positive experience.

There are three types of tasks in the manufacturing industry that people need training for–assembly line tasks, job shops, and discrete tasks. These tasks include monitoring the assembly line, sorting, picking, keeping, assembling, installation, inspection, packing, cleaning routine (process, shovel, sweep, clean work areas), and using hand tools, power tools, and machinery. After conducting user research and reviewing the literature of XR technologies for manufacturing training, and based on the different qualities and capabilities of VR, AR, MR, all the tasks can be broken

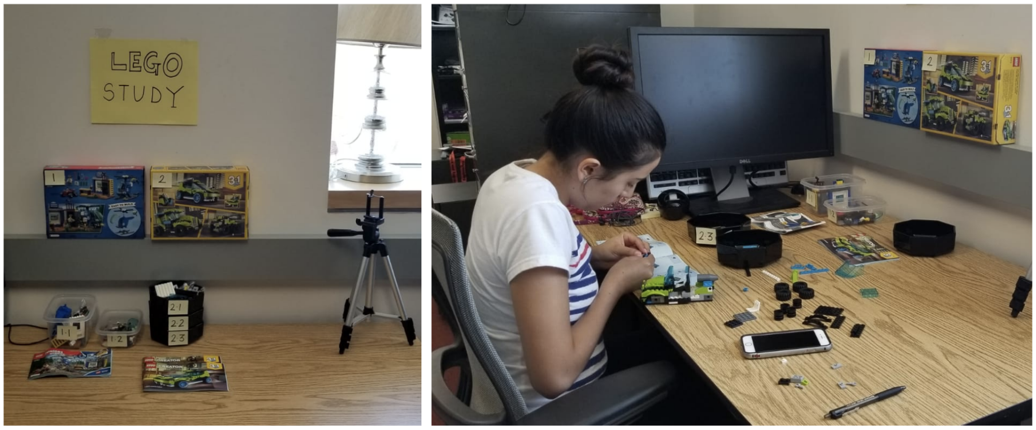

Figure 3.10. User Study setup for Lego Project.

Table 3.1. Manufacturing phases and when to use what XR technology for training [3]

Manufacturing Phases	**Tasks**	**Useful XR technology in training**
Introductory Phase	safety training, orientation training, planning and designing of new tasks	VR, MR
Operational Phase	inspection, packing, monitoring assembly line, assembly	MR
Tangent Phase	using rare tool/machinery, hand tool, power tool	AR, MR
End Phase	cleaning routine (process, shovel, sweep, clean work areas), inspection	AR, MR

down into different manufacturing phases and the XR technologies can be mapped to a task where they can prove beneficial, as shown in Table 3.1.

As evident in Table 3.1, VR is very useful in the introductory and learning phase. The most significant advantage of using VR for these phases is that it adds a virtual layer to training. This ensures worker wellness and keeps them safe from workplace risk or too many errors during learning. In addition, VR is also helpful for planning, visualizing and designing new training tasks.

As seen in the Reality–virtuality continuum (Chapter 1, Figure 1.1), MR is the most flexible technology and could be used in almost every phase. For example, in the manufacturing scenario, MR can be utilized for training in every phase. It is not entirely immersive like VR and lets the user view this real world and digital information. This is helpful in operational phases that include tasks that need to be done daily, a tangent phase that includes rare tasks that are occasionally needed, and an end phase that requires daily job shop tasks, like cleaning and inspection.

Much work is needed for AR technology to become helpful in all manufacturing phases. Therefore, AR needs some further development before it can work. Although it can help when used in few phases, it is still not effective as VR and MR presently. However, in situ projections can be considered as AR technology, and these have proven to be helpful in learning, tangent, and end phases.

3.5 Research Questions

Based on all the information, user data, and learning from these projects, I prepared research questions (Table 3.2) for more focused research. Storytelling literature review proves that it has been a universally accepted method of education, training, and learning. An immersive medium like virtual Reality also increases long-term recall and retention of information learned. [23] proves that second language acquisition

Table 3.2. An overview of the Research Questions addressed in this dissertation.

Research Question	**No**	**Chapter**
How should the story be told in VR?	RQ1	Chapter 4
Is IS better than normal task instructions?	RQ2	Chapter 4
How does interactivity help in learning process in vIS?	RQ3	Chapter 7
Does storyfication enhances user engagement in vIIS?	RQ4	Chapter 7
How can the vIIIS system become smarter?	RQ5	Chapter 8
What are the advantages of vIIIS over vIIS?	RQ6	Chapter 8
Guidelines to design smart training system.	RQ7	Chapter 10

in a virtual reality environment is better than traditional language learning methods. Therefore, I needed to investigate whether the combination of immersive medium and storytelling would prove better than already existing methods of learning a new skill. vIS - Vocational Immersive Storytelling method was investigated (Chapter 4) as a proof of concept. The following research questions are discussed and proven in this dissertation.

CHAPTER 4

vIS - VOCATIONAL IMMERSIVE STORYTELLING SYSTEM

This chapter is partly based on the following publication

- *Doolani, Sanika, Luke Owens, Callen Wessels, and Fillia Makedon. "vIS: An Immersive Virtual Storytelling System for Vocational Training." Applied Sciences 10, no. 22 (2020): 8143.*

While much research has been conducted on using Virtual Reality based training systems, none of them have explored the advantages of adding storytelling content to such systems to measure the impact on learning outcomes, user engagement, and long-term recall. In this chapter, vIS, a novel immersive virtual storytelling system for vocational training, is presented. The effectiveness of adding fictional story content inside an immersive virtual reality system designed to train users how to use a micrometer, an advanced tool whose demand for skilled knowledge exceeds the educational training, is investigated [95]. The system's capability to provide training suitable for long-term recall compared to traditional vocational training methods, text-based and video tutorial-based learning is also evaluated by conducting a two-phase user study of 30 participants spaced seven days apart. The usability and user engagement metrics of the vIS system against the traditional methods of training are also presented.

The analysis shows that the participants of the vIS system performed slightly better than 2D video-tutorial participants but outperformed the participants of the text-based training method in terms of long-term retention and recall of using a micrometer. In addition, data collected from post-training questionnaires show a high System Usability Score (SUS) [96] of 76 for the *vIS* system; an indication of a high degree of satisfaction in using the system compared to other traditional methods.

In the following sections, I present the relevant work in this space, describe the design of vIS System in detail as discussed in [29], design decisions behind the story content, and then report the insights of the user study followed by a discussion on the findings.

4.1 System Design

The vIS system bridges the gap between Virtual Reality and Storytelling by using an immersive virtual workplace environment and employing creative, non-interactive, fictional stories to provide vocational training. In this section, an overview of the skill training being provided is given, and then the two main components of the system: the story and the virtual workplace environment, are explained. The design decisions that went into the creation of the immersive story are also provided. The vIS system was design based on the vIS framework (Figure 4.1). The framework has three components:

- User - The user is the human component of this HCI framework. The user uses a virtual reality headset.
- Story - The story is non-interactive and view only in the virtual environment.
- Feedback - The user receives the feedback generated by the virtual environment through audio and visual feedback.

The system was implemented in Unity 3D with C# scripting, and animations were created in Cinema4D. HTC Vive Head-mounted display (HMD) for the training simulation was used.

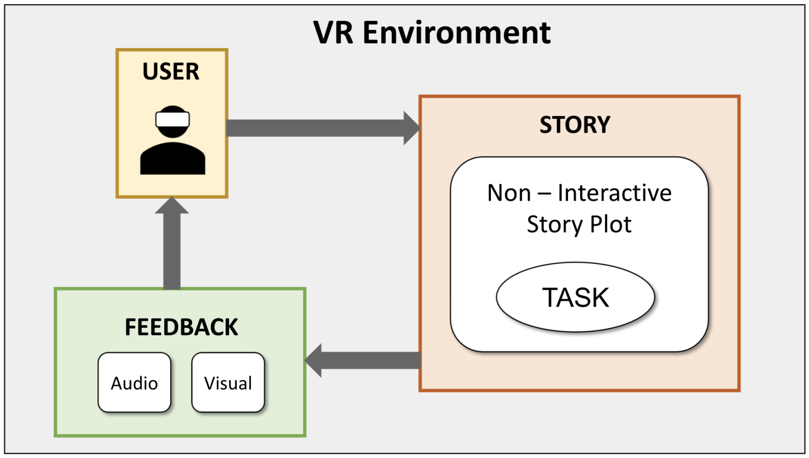

Figure 4.1. vIS Framework.

Figure 4.2. 3D model of an outside mechanical micrometer (vIS System).

4.1.1 Training Apparatus

The system to train users to use a mechanical micrometer, specifically an *outside micrometer* was designed. A micrometer is a measuring instrument used to make extremely precise measurements of objects and measure within one-thousandth on an inch. Such tools are essential in manufacturing environments where measurements of objects such as pipes, valves, or fittings need to be extremely precise to avoid potentially dangerous outcomes. An outside micrometer is designed to measure the

Figure 4.3. Storyboard of the immersive virtual storytelling training system (vIS System).

thickness or outside diameter of a small object. Figure 4.2 shows the 3D model of an outside micrometer used in the study.

4.1.2 Storytelling Content

Storytellers aim to create culturally and personally interesting content and tap into human desires for adventure, fear, arousal, drama, love, and hate. For immersive stories, authors not only need to utilize traditional narrative strategies - such as creating compelling characters, twisting the story plots, adding story arcs, but they also need to aid the viewer's perceptual experience with immersive interfaces. Keeping these principles in mind, I built upon the work of Ladeira et al. [39] by embedding sequential instructions of how to use a micrometer in a narrative structure so that the story plot precedes the instructions, and the skill training takes place during a story's character development phase.

4.1.2.1 Story Plot

The story starts from the outside of a manufacturing plant's workplace. David, a worker, is shown walking into the plant from the entrance. The floor of the plant is busy, with conveyor belts moving and workers walking past David and exchanging greetings. The scene is shown from a third-person perspective. David stops to look across the plan from left to right, looking for Remy. He spots Remy in the far right corner of the building. Remy, the story protagonist, is a plumber and is sitting at his desk. David walks up to Remy's desk; the sound of workers talking and the conveyor belt moving can be heard in the background. David stops at Remy's desk and begins chatting with him. A few moments later, a significant pipe bursts behind Remy's desk, causing water leakage. Remy rushes to stop the water from leaking by placing a temporary lid. David and Remy discuss, and they know the lid will not hold in place for long, so Remy rushes to find a replacement pipe to fix the leak. Remy tells David that he needs to cut a cylindrical cap precisely the size of the leak and tells David that he is willing to teach him how to use a micrometer to fix this problem in the future in case he is not in the office. The camera zooms in on the table where Remy sets up the anvil to demonstrate how to use the micrometer. Remy walks David through the entire procedure on using a micrometer on a cylindrical pipe, and when he finishes, he cuts the pipe in the right size and fixes the leaking pipe. David and Remy rejoice when the leak stops, ending the story on a higher note.

4.1.3 Immersive VR Environment Design

The virtual environment is based on a manufacturing plant's workplace. The environment has an active conveyor belt and multiple workstations spread across the plant, with many workers actively working and walking around. The two main characters in the environment are David, a factory worker, Remy, a plumber, and the story's protagonist. The virtual environment is not cluttered with all the components of a typical manufacturing plant, as I wanted to avoid causing any distraction to the viewer during the story runtime. The crux of the story plot occurs around Remy's desk. An anvil and a mechanical micrometer can be seen positioned at his desk. Behind his desk is a water pipe which will be the center of the story's hook. All the characters in the environment have very natural features. Their movements and expressions resemble that of an actual human being, keeping the entire experience as immersive as possible. The animations of the characters were done in Cinema4D and then imported into the virtual environment in Unity 3D.

4.1.4 Design Decisions

Many design decisions were made to create a suitable fictional story. I started with storyboarding and made multiple iterations over the story's design to create a story that delivers the training information in the right way and elicits the user's right emotions to aid in the long-term recall of the training content. Figure 4.3 shows the critical scenes of the final storyboard.

Design Decision #1 – Story format: The format of a story plays a huge role in how well the viewer stays connected and engaged with the story content. In order to keep the story length short and avoid adding complications, I chose the most common form of narrative fiction, a *three-act structure*, which divides the story into three parts:

1. *The Setup:* This is used for exposition where the characters, the protagonist, their relationships, the environment setting, and all relevant background information are laid out to the viewer.

2. *The Confrontation:* Usually triggered by an onset of an unexpected event, termed as Complicating action, followed by which the protagonist attempts to resolve the problem by learning a new skill(s), often referred to as character development.
3. *The Resolution:* Part of the story that features the resolution preceded by the story's climax.

Design Decision #2 – The Complicating Action: Commonly referred to as the story's hook, I needed to pick the suitable event to elicit the right emotion of the viewer. Emotions play a massive role in learning[97], and eliciting the right emotions helps to remember the events following the complicating action even longer. Given that the story background was a virtual manufacturing plant's workplace and the task was to train users on using a micrometer, I ideated on multiple complicating actions. Then, I tested them using empathy maps, an essential tool used in the Design Thinking Process. Finally, I decided on a significant pipe burst event causing water leakage to be the complicating action to disrupt the flow of the story.

Design Decision #3 – Visual Perspective: In Virtual environments, the two main types of perspectives available are first-person perspective (1PP). The camera is in the viewer's eye, and third-person perspective (3PP), in which the camera is at an adjustable distance and angle of view. The decision to choose between 1PP and 3PP was a crucial one. I iterated over multiple versions of the story where I tested different combinations of perspectives like 1PP, 3PP, and a combination of 1PP and 3PP. I found that 3PP worked well for the immersive story, and prior research in 1PP vs. 3PP for VR-based training [98] also confirmed that users prefer 3PP as it makes it easy to perform spatial navigation in the virtual environment. Furthermore, on testing the 3PP design prototype, users said it gave them a sense of control and safety when introduced to a new environment.

Design Decision #4 – Camera movement: I designed the camera movement to allow the viewer to quickly focus on the main components of the story and have the freedom to look around the surrounding environment in the viewer's field of vision through head movement only. The viewer could not move within the environment. As Virtual Reality is highly immersive and has a 360-degree view, it was essential to design an experience that focuses the viewer's attention on the main activities in the story. Instead of deciding on just one type of camera movement, I decided to use a combination of two different camera movements. At the beginning of the story, the viewer had control over the camera movement as the character was slowly entering the factory, giving the viewer an ability to move their head and see the overview of the environment. At the time of training, the free head movement was minimal, ensuring that the viewer pays attention to the micrometer training and not getting distracted by other environmental elements.

The speed of the camera movement during the story flow was decided, and the resulting video was at 35fps after multiple iterations of testing with users to avoid causing any unease to the user.

Design Decision #5 – Sound: An immersive story is impacted less without a good sound design. Sound plays a huge role in how the user interacts, engages, and consumes the information from a story. Salselas et al. [99] reviewed the literature on the role of sound in immersive storytelling. They found that a good sound design modulates a viewer's attention in a way that allows for an immersive user experience and allows the viewer to deduce that a narrative is being followed. I added sound for the factory environment, workers talking and working with heavy equipment. When the main characters were having a discussion, I reduced the background noise to focus on the character dialogues.

Design Decision #6 – Embedding Training Material: Adding the training material for using a micrometer in the story was critical to allow for long-term recall. On the other hand, I wanted to avoid creating the story to make it look like a glorified instructional video or creating too informal of a storyline that the viewer would not focus on the training material. To strike the right balance, I took the help of a few specialized vocational training instructors who helped us craft the story dialogues to connect with the main characters in the story. In the story, the main character talks aloud about how he plans on fixing the broken pipe and walks the viewer through the various steps in using a micrometer and calculating the width of a pipe needed to fix the leakage.

4.2 Research Questions

To test the effectiveness of the system, I conducted a training and recall study to answer the following research questions:

1. **R1:** Can users effectively use the *vIS* system to learn a new skill, in the case of learning how to use a micrometer and be able to apply it immediately after training.
2. **R2:** Can users of the *vIS* system recall the learning a week after the training?
3. **R3:** Is the overall effectiveness and usability of the *vIS* system better compared to traditional training methods: text-based manuals and 2D video training?

To determine the usability of the *vIS* system to inform future design decisions, a System Usability Scale (SUS) [96] was administered to all the participants.

4.3 Study Design

In order to empirically evaluate the above research questions, I developed a between-subjects experiment in which participants were allocated, in the round-robin, to one of the three training methods:

1. **vIS:** In this method, the participants were given HTC Vive headsets and a headphone to view the immersive story. The immersive story was 2 minutes and 50 seconds long.
2. **2D Video:** The participants were given a 2D tutorial video, without any storytelling components, which explained all the steps of using a micrometer. The video was 3 minutes long.
3. **Text Manual:** A traditional method of learning a new skill; the participants were given an instructional manual that outlined all the steps of using a micrometer. The manual contained pictures of components of the micrometer along with the usage steps. The manual length was two pages. No storytelling elements were included in this manual.

In all the above methods, the participants were given the freedom to repeat the training until they felt confident using a micrometer. To measure the learning and recall of these methods, the user study was divided into two phases with a gap of seven days between both phases.

- **Day 1:** Training session. Participants were assigned to one of the training methods mentioned above, where they interacted with the assigned system until they felt confident in using a micrometer. Once the training was complete, they were given a cylindrical object and a micrometer. They were asked to measure the object's diameter using the same steps taught in the training material. In the end, their answers, along with the SUS scale responses, were then collected.

- **Day 7:** Recall Session (seven days after a training session). Participants were asked to calculate the diameter of the same cylindrical object, and their answers were collected.

The study was conducted on a University of Texas at Arlington's campus, in a controlled lab environment, and was approved by the university's Institutional Review Board (IRB). I recruited participants via word of mouth. During the study, only one participant indicated having some knowledge on how to use a micrometer.

4.4 Evaluation

4.4.1 Study Procedure

4.4.1.1 Training Session.

Participants were presented with an Informed consent form. After giving consent, they were assigned to one of the three training methods in the round-robin style and explained the study's aim. They were given the freedom to repeat the training any number of times they wanted until they felt confident using a micrometer. At the end of the training, they were given a round cylindrical object and were asked to measure the object's diameter. They were then given an online form where they had to submit their answer and fill out a questionnaire to capture the SUS scores.

4.4.1.2 Recall Session.

Participants returned for a follow-up study after seven days of completing their training and were presented with a different cylindrical object. They were asked to calculate the diameter of the object and submit the answer in the online form.

4.4.2 Data Collection

To evaluate the usability and effectiveness of the system, I collected the following types of information throughout this study:

- Demographic information of all the participants.
- The number of times each participant repeated their training in the Training Session.
- Total time taken by each participant to complete the training.
- Total time taken by each participant to calculate the diameter of the object post-training in the Training session.
- Accuracy of their calculations in Training Session.
- Responses to the SUS questionnaire post Training.
- Total time taken by each participant to calculate the diameter of a different object in Recall Session.
- Accuracy of their calculations in Recall Session.

4.5 Results

As already pointed out earlier, the purpose of the usability study is to assess the effectiveness and long-term recall rate of *vIS* and compare it against the traditional methods of training. Therefore, I conducted a one-way analysis of variance (ANOVA) to test statistically significant differences between the three different training methods. Then, I conducted a turkey post hoc test to reveal where does the significance lies. Wherever possible, I also depicted the data analyzed using box-and-whisker plot diagrams.

4.5.1 Demographics

Thirty adults participated in the usability study. Most were students at the university from various degree programs; none had any prior experience with vocational training. Only one of them identified as having some prior knowledge of using a micrometer but were not confident in recalling the steps when asked. Among those who reported their age, the age range varied between 19 to 45, with a mean age of 25.85. In addition, 70% of participants identified their gender as male, and 30% identified as female.

4.5.2 Training Time

I measured training time as participants take the total time to complete the training session. Since participants were allowed to view the training material any number of times until they felt confident in using a real micrometer, this time includes the addition of time for all their attempts to view the training. This time was calculated manually by the usability study invigilator using a stopwatch. Table 4.1 summarizes the training time for all three training methods.

There was a statistically significant difference in the training time between the three training methods, as determined by one-way ANOVA [$F(2, 27) = 11.65914$, $p = 0.000224$]. Furthermore, a turkey post hoc test revealed that training time was

Table 4.1. Training time of all three training methods in seconds (vIS System)

Training Method	**Mean**	**Median**	**Std Dev**
vIS	289	340	82.11
2D Video	196.8	197	24.86
Text Manual	455.9	367	192.40

Table 4.2. Post-training measurement time comparison of all three training methods in seconds (vIS System)

Training Method	**Mean**	**Median**	**Std Dev**
vIS	140.128	126.23	31.50
2D Video	143.339	129.87	34.89
Text Manual	177.248	164.68	74.73

statistically significantly lower in *vIS* compared to the manual textual method, p¡0.05. There was no statistically significant difference between the *vIS* method and the 2D video training method.

4.5.3 Post-Training Measurement Time

I measured this as the time taken by the participant to calculate the diameter of a cylindrical object using a micrometer immediately after completing the training session. This time was calculated manually by the usability study invigilator using a stopwatch. Table 4.2 summarizes the measurement time comparison of all three training methods.

I observed no statistically significant difference in the measurement time for all three training groups.

Table 4.3. Recall measurement time comparison of all three training methods in seconds (vIS System)

Training Method	**Mean**	**Median**	**Std Dev**
vIS	209.5	205	14.01
2D Video	213	213	11.16
Text Manual	223.9	221	10.81

4.5.4 Recall Measurement Time

I measured this time as the time taken by the participant to calculate the diameter of the same cylindrical object during the recall session, exactly one week after their training session. This time was calculated manually by the usability study invigilator using a stopwatch. Table 4.3 summarizes the recall measurement time comparison of all three training methods.

Contrary to the Post-Training Measurement Time, I observed a statistically significant difference in the one-way ANOVA test [F(2, 27) = 3.86, p = 0.033542]. Turkey post hoc test revealed a statistically significant difference, p¡0.05, between *vIS* and text manual training method, and no statistical significance between *vIS* and 2D video method.

4.5.5 Training vs Recall Measurement Accuracy

The accuracy of the measurements was calculated using the formula:

$$\frac{|V_a - V_o|}{V_a} \times 100 \tag{4.1}$$

where V_a is the acceptable value of the cylindrical object, and V_o is the measured value of the cylindrical object. Before starting the usability study, I calculated the acceptable value of the cylindrical object by performing ten measurements and taking the average of these calculations to the nearest thousandth of an inch. I then compared

Figure 4.4. Training vs Recall Measurement Accuracy (vIS System).

the participants' measurements against the acceptable value and calculated every participant's accuracy percentage for both sessions.

Figure 4.4 shows the comparison of measurement accuracy during the training and recall session. While no statistically significant difference was observed in the accuracy during the training session, I observed a significant difference in the recall session [F(2, 27) = 2.54, p = 0.047554]. Furthermore, Turkey post hoc test revealed a statistically significant difference, p¡0.05, between *vIS* and 2D Video, and *vIS* and text manual method.

4.5.6 SUS Survey

In the survey, I asked the participants to answer the System Usability questions on a 5-point Likert scale (1: Strongly Disagree, 5: Strongly Agree). Overall, the average SUS score for *vIS*, 2D Video and text manual was 76, 72, and 62, respectively. A SUS score of 68 and above is considered above average. The maximum SUS score was 100. These scores show that while participants of the text manual group indeed did not find the method usable, participants of *vIS* method perceived the system's usability to be higher than that of the 2D video method.

4.6 Discussion

Virtual Reality training systems are now starting to become commercially available. However, the study of combining storytelling narratives in an immersive training system has been largely unexplored. The *vIS* system explores a promising new direction to improve the long-term memorability of the training material by embedding the training instructions inside a fictional narrative. This is a first-of-its-kind unique virtual reality-based system, which compares extremely well to traditional learning methods.

From the training session time, it can be seen that the text manual method had the most extended training session, whereas the 2D video method had the shortest length. While the *vIS* group took roughly a minute and a half longer than the 2D video method, it is worth noting that the storytelling system had the instructions embedded inside a story. Hence, it was expected to take slightly longer than 2D video. While statistically, there is not much significance between the storytelling system and 2D video, *vIS* clearly outperformed the text manual method of learning. This is in line with the expectations of previous work, such as by Chao et al. [100] where the VR training was considered the best compared to technical manuals.

The results of the post-training measurement task showcase the ability of humans to recall instructions from their short-term memory. As described by Atkinson et al. [101], retrieval of information from the short-term memory store is quite fast. Hence I saw a nearly ideal and equal measurement time in the storytelling system and 2D video method. A very high measurement time for the text manual method was surprising, as I expected the time to be nearly equal to the other methods.

It is interesting to see the long-term memory recall result in the measurement time during the recall phase, as measurement times increased after a gap of seven days, clearly a sign of the complication in retrieving information from the long-term memory store as described by Atkinson et al. [101]. I saw that the measurement time of participants from the *vIS* group was the shortest among all the methods, proving the power of storytelling in aiding in the long-term recall of training instructions. I expected the measurement time of the 2D video to be less than that of text manuals, as video-based training has been proven to be a more robust tool in encoding information for long-term retention.

In conjunction with the measurement time observed during the recall phase, the significance of the storytelling system's capability to provide long-term training can also be found by comparing the accuracy of measurements in training and recall sessions. As evident by Figure 4.4, although the accuracy dropped for all the methods in the recall phase, the accuracy of measurements remained consistently higher for *vIS* system compared to the traditional methods. A statistical difference of p¡0.05 proves that the immersive storytelling system performed exceptionally well in the long-term retention of training material.

These results demonstrate that while the training system fares equally compared to traditional training methods, I started to reap the benefits of adding the storytelling content in the long-term recall of the training content. Although *vIS* users had statistically insignificant recall times compared to other methods, I put more weightage on the combination of recall time and measurement accuracy in recall sessions because a pair of these variables is what defines a usable training system. *vIS* performed better than other methods regarding a combination of these two variables.

Clearly, *vIS* has a lot of usability potential, as shown in the post-survey questionnaires pointing to a higher than average SUS score. Further evaluation of the system is needed with a more significant number of participants to verify the findings.

4.6.1 Study Outcomes

To increase the skill level of a country's population, the need for a cost-effective vocational training solution has risen in the last few years. While there exists several virtual reality-based training systems, the field of immersive storytelling-based training systems has largely been unexplored. In this paper, I presented vIS, the first-of-its-kind virtual reality-based immersive storytelling system that employs storytelling as a medium to impart training to users. The system focuses on teaching users how to use an industrial micrometer. I conducted a user study with 30 participants to evaluate the system's effectiveness in providing long-term training and compared it against traditional forms of training: 2D video and text-based. The results show that the use of storytelling inside a virtual environment is very effective against text-based training, equally effective compared to 2d video-based training, and more engaging to users than 2D video and text-based techniques.

vIS is the first step towards using storytelling for immersive training; hence I only compared its effectiveness against the traditional forms of training and required the user to practice with the micrometer outside the virtual environment. In the next step, I intend to add interaction inside the virtual environment and bridge the interaction with the ongoing story to make it a seamless, immersive experience. The far-reaching goal is to enrich the vocational training system with an intelligent story in an immersive environment where users can interact with the environment and get trained on-demand without the need for in-person training. I also learned how to design a story in an immersive environment.

CHAPTER 5

MEMORY

This chapter is partly based on the following publications

- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2021. Designing a Vocational Immersive Storytelling Training and Support System to Evaluate Impact on Working and Episodic Memory. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA Sanika Doolani, Callen Wessels, and Fillia Makedon. 2018. vIIIS: A Vocational Intelligent Interactive Immersive Storytelling Framework to Support Task Performance. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA.*

5.1 Working Memory

The multi-component approach to working memory which includes, phonological loop, central executive, and episodic buffers, tries to understand how the task information is stored and maintained in the performance of complex cognitive processing [102] as shown in Figure 5.1. It is also known as short-term memory. The information while doing a repetitive task is stored in the working memory [103] Flow is essential to maintain high levels of engagement during any task. It is associated with

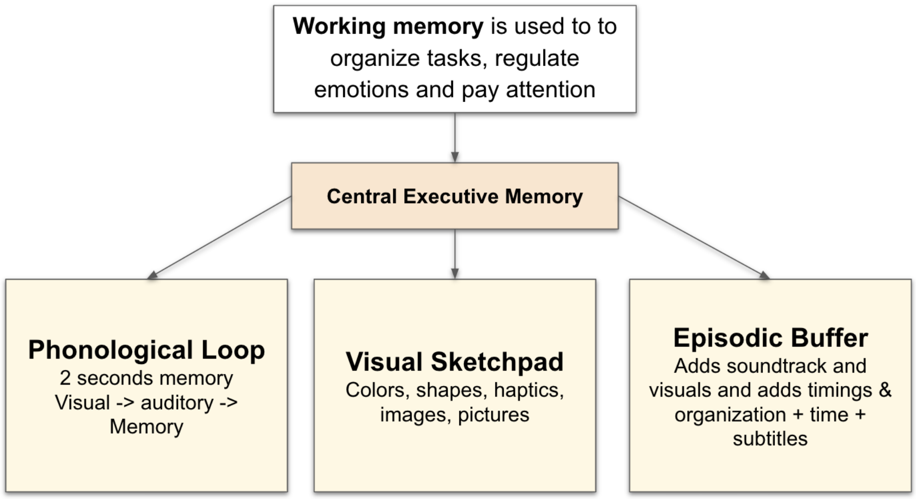

Figure 5.1. Working Memory Model proposed by Baddeley and Hitch, 1974 [2].

factors such as sense of control, action awareness merging, loss of self-consciousness, concentration on activity, distorted sense of time, and rewarding experiences.

5.2 Episodic Memory

Episodic memory is built of story components. Therefore procedural tasks work best for it. Any continuous task enhances the role of episodic memory. It is also known as long-term memory. Episodic memory creates a representation of events where the information is linked to its details. Storytelling enhances this experience for the user [104] The richness of the representation is helpful to retrieve episodes of the events. Contextual details can serve as cues to help to remember the information [105]. Many factors affect temporal and spatial information, affective conditions, cognitive operations, physical characteristics of objects, and presentation modality. There is a link between episodic and working memory as the information translates from short term to long term as shown in Figure 5.2.

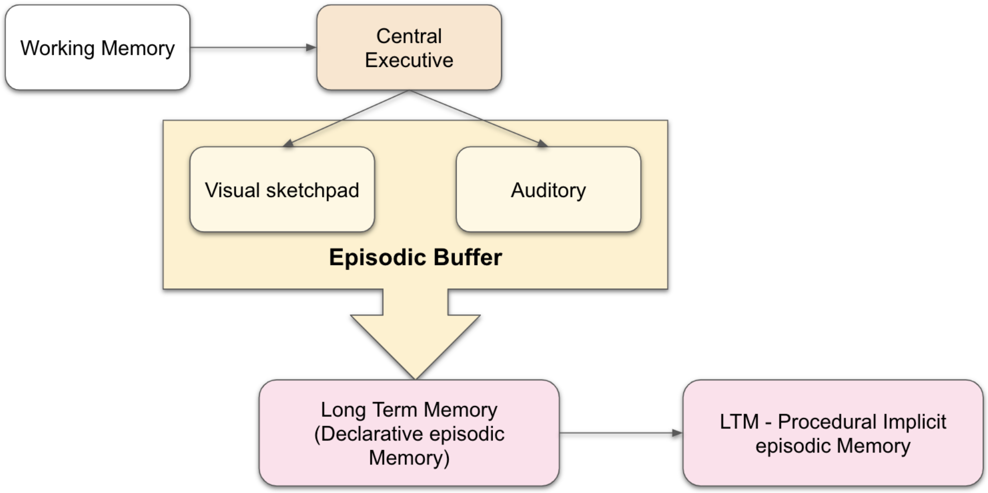

Figure 5.2. The current model of working memory, revised to incorporate links with episodic (long-term) memory by Baddeley and Hitch, 2000 [2].

5.3 Types of Training Tasks

The cognitive attributes required for industrial training are organizing thoughts, handling time pressure, complex tasks, tests, learning new tasks, confusion, making decisions, too many tasks to do, remembering info, pattern recognition, multitasking, concentration, multitasking, concentration, the information presented slow and fast. In addition, factory workers' tasks include monitoring assembly line, sorting, picking, keeping, assembling, complete procedures like assembly-installation-inspection-packing-process-shovel-sweep-clean work areas, cleaning, using hand tools, power tools, machinery.

For example, consider the scenario of a Walmart worker. The tasks of this worker are to learn how to use a scanner, machine, trolley, learn how to do X no of jobs such as putting things on shelves, the package for pickup delivery, maintaining fresh produce, procedures and to learn how to categorize, organize [repetitive tasks such as sorting, picking, monitoring, inspecting]. These are three categories into

Table 5.1. Types of Tasks for Vocational Training

Task	**Frequency**	**Type**	**Example**
Learn step by step one task (A)	Learn once /doing occasionally	Step by Step Sequential Task	Using a tool/machine
Learn methodical set of work (A-B-C-D)	Learning once /Doing daily	Step by Step Sequential Task	Doing a set of tasks to finish a job
Learn disassembly, sorting, cleaning	Everyday / Everytime	Repetitive Non-Sequential Task	Repetitive tasks like sorting, cleaning

which the tasks can be divided. Table 4.4.1.2 describes the three categories of tasks, their frequency with which these tasks need to be done, and their type - how these tasks can be accomplished.

Step is one activity in a set of activities to finish a task.

$$\text{Task} = \text{X number of Steps}$$

$$\text{Job} = \text{X number of Tasks}$$

$$\text{Work} = \text{Job (Tasks (Steps))}$$

The current training methods are video, in-person instructions, manual, training period, classes, and learn by doing. The goals of industry and factories are to reduce cost, increase the retention rate of workers, fast and practical training, safety, and wellness of workers.

5.4 Use Cases

5.4.1 Use Case #1 - Teaching a new Skill

Training systems can be used to teach new and already experienced workers in learning how to conduct a new task. The ability to conduct the task with maximum accuracy and precision depends on how well the worker has learned the new skill. Instead of learning from another worker, the training system designed in this dissertation aims to teach the new worker directly the task or skill by placing the worker in an immersive environment. The instructions, tasks, or skills are taught using storytelling. [106]

5.4.2 Use Case #2 - Adaptive task to support user

Continuous quality support is the key to the high retention of skilled workers in the workforce. As the technologies are evolving rapidly, the need to train, re-train, and support workers is higher than ever. Therefore, there is a need for training systems at the workplace that provide continuous support for workers. This could be helpful if the task is cognitively demanding.

The study's goal is to examine whether the training in an Augmented Reality environment outperforms a web-based training interface to train the user how to work at the factory by improving their episodic and working memory. For this, I have designed two tasks – picture sequence and object sorting. These tasks are inspired from NIH Toolkit [107].

5.5 Task selection

The task selection was based on the use cases of the project. A use case is a detailed scenario of how users will engage with the system. It outlines the training system's behavior, specifications, details, and benefits, and how the system will respond to the user's input. In this dissertation , I have two use cases with specific goals. I have assigned tasks for each of the use cases based on their requirements and conditions. Training systems can be used to train, educate and inform several information in assembly and factory workplace. Therefore I have defined use cases that will help us investigate this dissertation , benefit from using a use case defined training system, and narrow down the search of answers to defined research questions. The task for Working memory used in this study is object sorting. Long-term memory, also known as episodic memory, will use the picture sequence task. The tasks are based on the picture sequence and object sorting tasks by the National Institute of Health (NIH) Toolbox. The NIH Toolbox is a set of predefined, ready to use neuro-behavioral measurements that quickly assess cognitive, emotional, sensory, and motor functions from the convenience of an iPad. The NIH Cognition Battery was used to select and design the tasks for working and episodic memory. The NIH Toolbox Cognition Battery, recommended for people aged seven and up, consists of multiple build tests.

- NIH Picture Sequence Task (Task 1 for Episodic Memory): Cognitive processes involved in the acquisition, storage and retrieval of new information (Figure 5.3)
- NIH Object Sorting Task (Task 2 for Working memory): Working memory tasks improves the ability to store information till a certain capacity until the amount of information to be stored exceeds one's capacity to hold that information (Figure 5.4).

Figure 5.3. NIH Picture Sequence Task.

These are the two tasks finalised for our systems in the further chapter (Chapter 7,8,9). **Task 1:** The first task is to train the user to work at a toy factory. The Picture sequence task will be used for Task 2. The user will be shown a sequence of tasks as pictures- how to assemble toys, how to use a machine, and how to make toys, and then they would be asked to repeat the steps correctly. Picture Sequence Task consists of 3 sequences. The first one is toy assembly. The second one is using a compressor machine to make the toy. The third sequence is a combination of the first two sequences with more steps. This task targets episodic memory.

Task 2: The second task is to train the user how to sort toys in size order in a toy factory. Object Sorting task will be used for Task 2. The user will be asked to sort six objects in size order in increasing order. This task targets working memory. The working memory object sorting task consists of sorting toys to match package shapes. The tasks consist of 6 toys that need to be sorted in increasing size order.

Based on the information learned from the user interviews, field research, investigatory project (Chapter 3) and the vIS proof of concept project (Chapter 4), I realized an effective vocational training platform will be one that ensures long term memory and improved attention and engagement. I finalized the two tasks inspired from NIH toolkit.

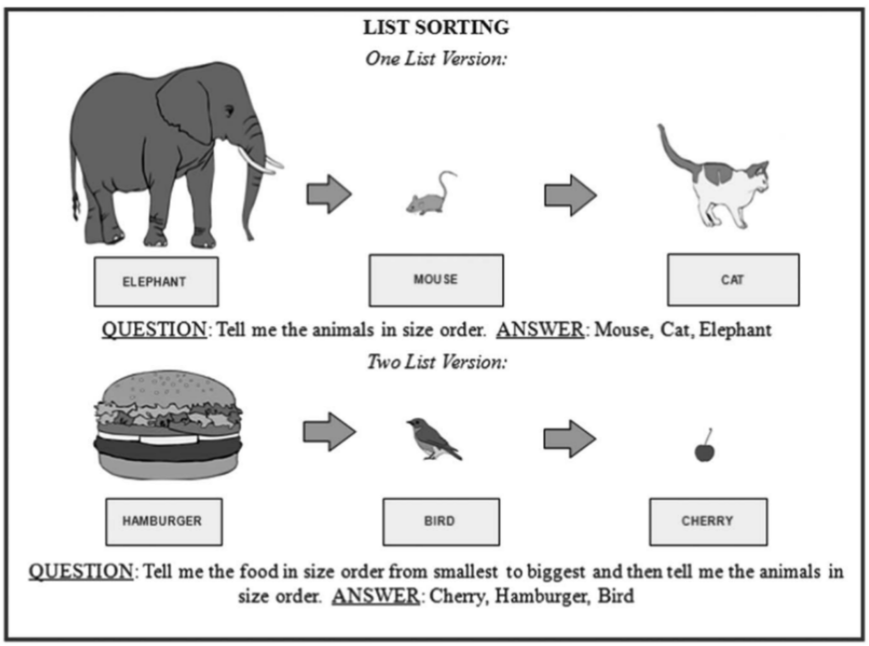

Figure 5.4. NIH Object Sorting Task.

CHAPTER 6

STORYFICATION

This chapter is partly based on the following publications

- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2021. Designing a Vocational Immersive Storytelling Training and Support System to Evaluate Impact on Working and Episodic Memory. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA*
- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2018. vIIIS: A Vocational Intelligent Interactive Immersive Storytelling Framework to Support Task Performance. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA.*

6.1 Storytelling Models

The first task in creating any story is to create a story theme and its narrative. The narrative is the entire story, and the plot is a section of the story. While the terms story, plot, and narrative seem to be similar concepts, there are subtle differences between these as explained in the [108]. An event is a scene or incident that takes place in a story. By itself, a single event does not create an emotionally engaging story. Instead, a story is formed by combining a sequence of events in a string, which creates an emotionally engaging experience. The plot of a story is how the story's events are linked to create a meaningful and emotionally engaging scene. Often, a story will have the main plot and one or more subplots. The subplots can further have subplots. The narrative of the story is how the events of the story are presented to the viewer. A given story with a particular theme and a given plot can be presented as different narratives, each having a somewhat different impact on the audience. There are several models for creating digital stories by selecting suitable events, creating compelling plots, and presenting these as the most engaging narratives. This section presents an overview of some of the essential storytelling models that aim to support the creation of impactful stories. Themes are one line that defines the story. Choices are impacts, rewards, and risks in the story that is called stakes. The elements of any story are story concept, characters scenes (beats), storyboarding, dialogue, sound, non-interactive parts, and interactive parts.

The narrative is how a story is told. Events are incidents; the story is a bunch of events, the plot is a series of events (E1-E2-E3-E4-E5-E6). The subplot is E1-E2, E7-E8-E9. The dramatic question is what makes the main point of the story and moves it forward (Figure 6.1).

There are linear and non-linear story models. *Dramatica* is a framework suitable for creating multimedia stories that focus on how the various story characters dramatize the narrative [109]. Dramatica guides the writer to create a credible and accurate story. It allows the creator to write scenes used for linear stories. In Dramatica, a story is called the "story mind." The authors can express their ideas, experiences, and knowledge in the form of a linear story in which the chosen aspects of the story are populated with suitable content.

The Adaptive Digital Storytelling (ADS) model allows a flexible story-schema that the user can adapt before entering the story [110] Hypermedia Novel is an extension of the graphic novel and provides a higher degree of interactivity for the user.

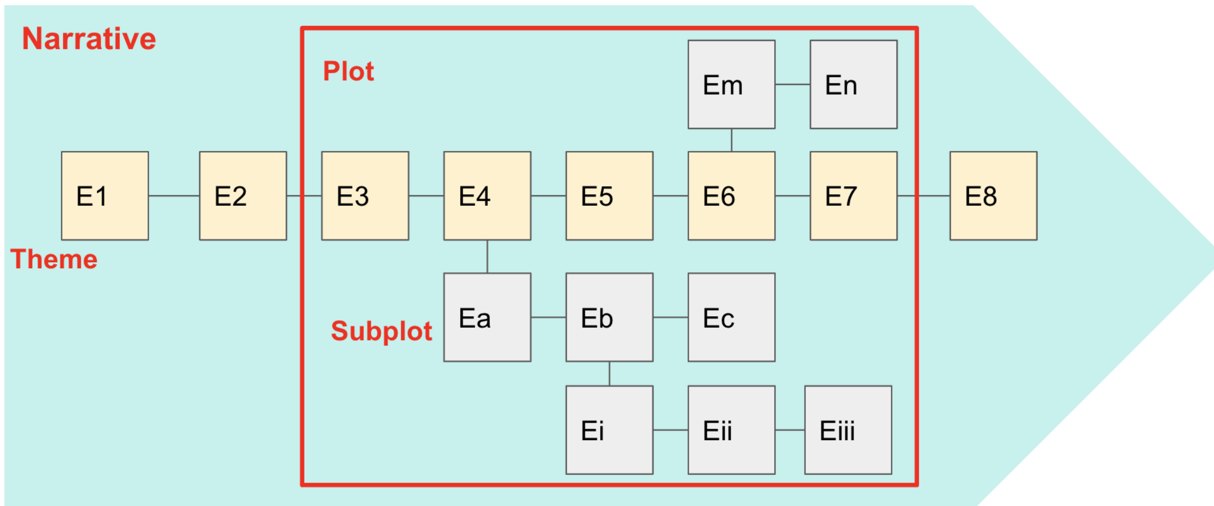

Figure 6.1. Story Narrative, Plot, Subplot and Theme.

It allows the structuring of the narration modules randomly in a story graph. [109]. *Digital Storytelling Cookbook (DSC)* is considered as a handbook for the creation of digital stories based on the heuristics gathered in a community of storytellers [109].

Digital Storytelling cookbook model:

1. Point of view
2. Dramatic Q
3. Emotional content
4. Author's voice
5. Soundtrack
6. Economy of story events
7. Pace and Rhythm of story

Movement Oriented Design (MOD) provides a systematic process for developing a training story starting with just a training topic or idea. The core element of the MOD methodology is a micro-story with its Beginning (B), Middle (M), and End

(E) components [108] MOD model is suitable for linear and non-linear stories. They have elements like Motivation - why Need- what, Structure - how, Beginning, middle and end, Environments, Character, Middle - challenge and conflict, Sound, dialogues, visuals, Rhythm pace, and Interactive parts any.

The story creates scenes. Scenes are easier to remember as compared to facts. Therefore, learning with stories is easier to remember and far longer. There are three types of learners, audio, visual and kinesthetic. Storytelling does three things -

1. Teaches: for example, memorable illustrations (it has a central point)
2. connect with learners: personal story (to build trust and mental breaks)
3. and move people to action - teach how to do something. Every story should have success, failure, and moments of clarity

$$\text{Ex} = \text{Events}$$

$$\text{E4,6} = \text{Choices/stakes}$$

$$\text{(N-X+1) Ex} = \text{Story}$$

6.2 Gamification vs Storyfication

Gamification is the application of game-design elements and game principles in non-game contexts. Games and game-like elements have been used to Educate, Entertain and Engage for thousands of years [111]. The goal of gamification is to motivate and engage. It breaks the game into fundamental elements. Consider a board game. The components of a gamified system are:

- Game space (Boardgame): This builds the context, which is the story.
- Game elements (Boardgame features): They reveal the information to the player, which becomes the rules of the games.

Figure 6.2. Spectrum of Learning.

- Elements of chance (dice/spinner): This brings an element of chance, unpredictability, and mystery in the game.
- Pieces: They can be in the form of avatars or characters.
- Spaces on the board: These spaces are used to reward the player
- Points, and digital badges are used in place of space.
- Competition and cooperation among players are used.

Gamification uses game-based mechanics, aesthetics, game thinking to engage, motivate action, promote learning and solve problems in a non-game context. Gamification is applying game mechanics, elements, and game thinking when designing instructions to apply:

- Help move learner through instructions
- To alter the content of the instructions

On the spectrum of learning (Figure 6.2), the extreme left end consists of formal learning mostly used in educational institutions. They contain exam questions for which the learner gets points. Games are on the extreme right side of the spectrum. They are purely fun and entertaining experiences with a storyline. Usually, every game has a storyline. The learner gets immersed in the game experience without a learning goal. In the middle, gamification exists, combining learning and game-based

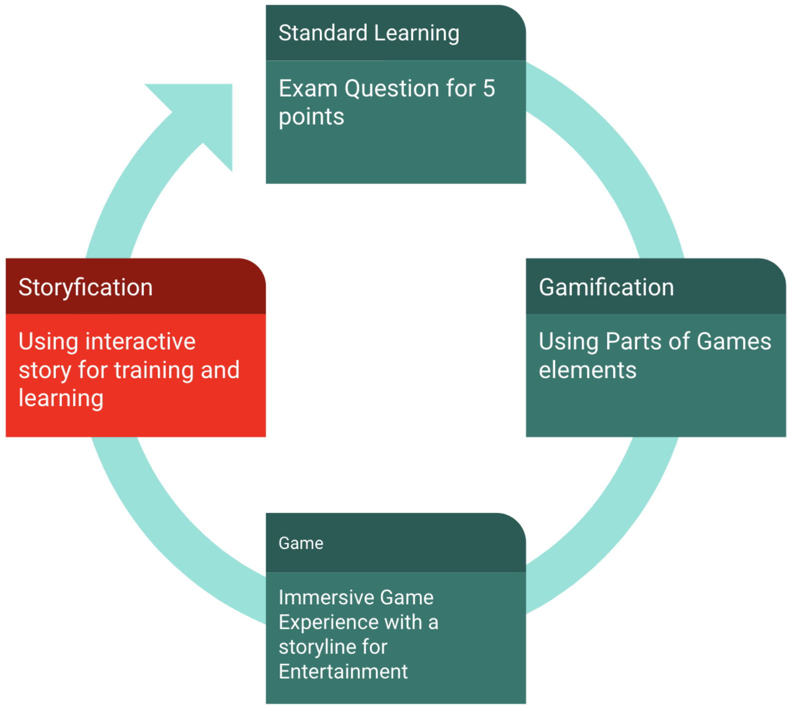

Figure 6.3. Circle of Learning.

features to make the learning experience engaging and motivating for the users. Figure 6.3 depicts the circle of learning. Storyfication fills the gap between formal learning and an enjoyable story-based game experience. Storyfication allows embedding a learning experience in a story that is created purely for learning and training purposes. The story plots and storyline depend on the input by the user.

While gamification is the process of applying game elements for training, Storyfication is designing an interactive story suited for training. This can be applied to create any story. In addition, it directly impacts episodic (long-term) and working (short-term), thus increasing engagement, attention, and the retention of information.

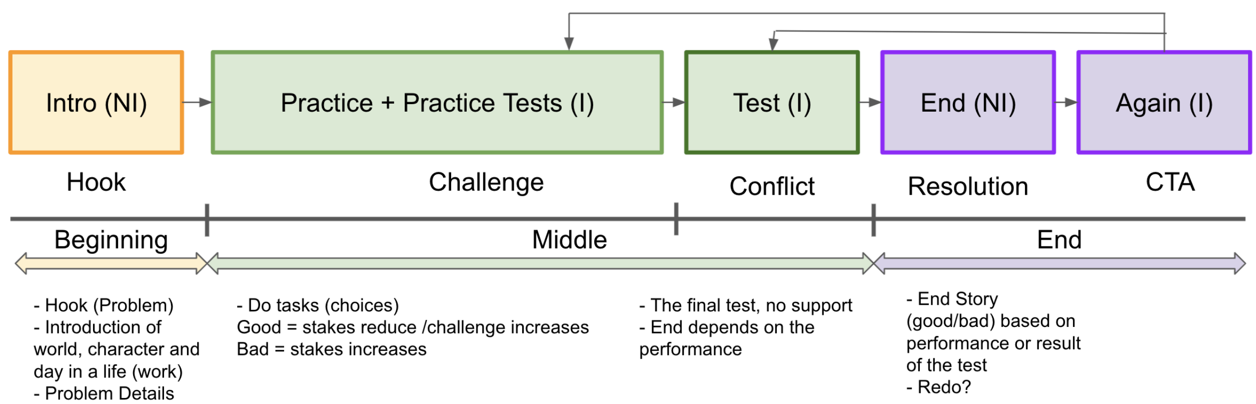

Figure 6.4. Storyfication Framework.

6.3 Storyfication Framework

The storyfication framework is inspired by the Movement Oriented Design (MOD) storytelling model suitable for linear and non-linear stories. The storytelling graph (Figure 6.5) depicts the progression of a narrative in relation to the stakes in the story. As the story progresses, the stakes get higher, thereby increasing the emotional responses of the user. This storyfication framework consists of the basic beginning, middle, and end sections (Figure 6.4).

1. **Beginning**: This section consists of a hook that gives a glimpse of a problem to immediately engage the user's attention. It gives an introduction to the world, character, and day in the life (work). The beginning section also describes the problem in detail later on and gives a call to action (CTA) option to the user. This is the first interaction of the user with the story. This is the non-interactive (NI) story plot.

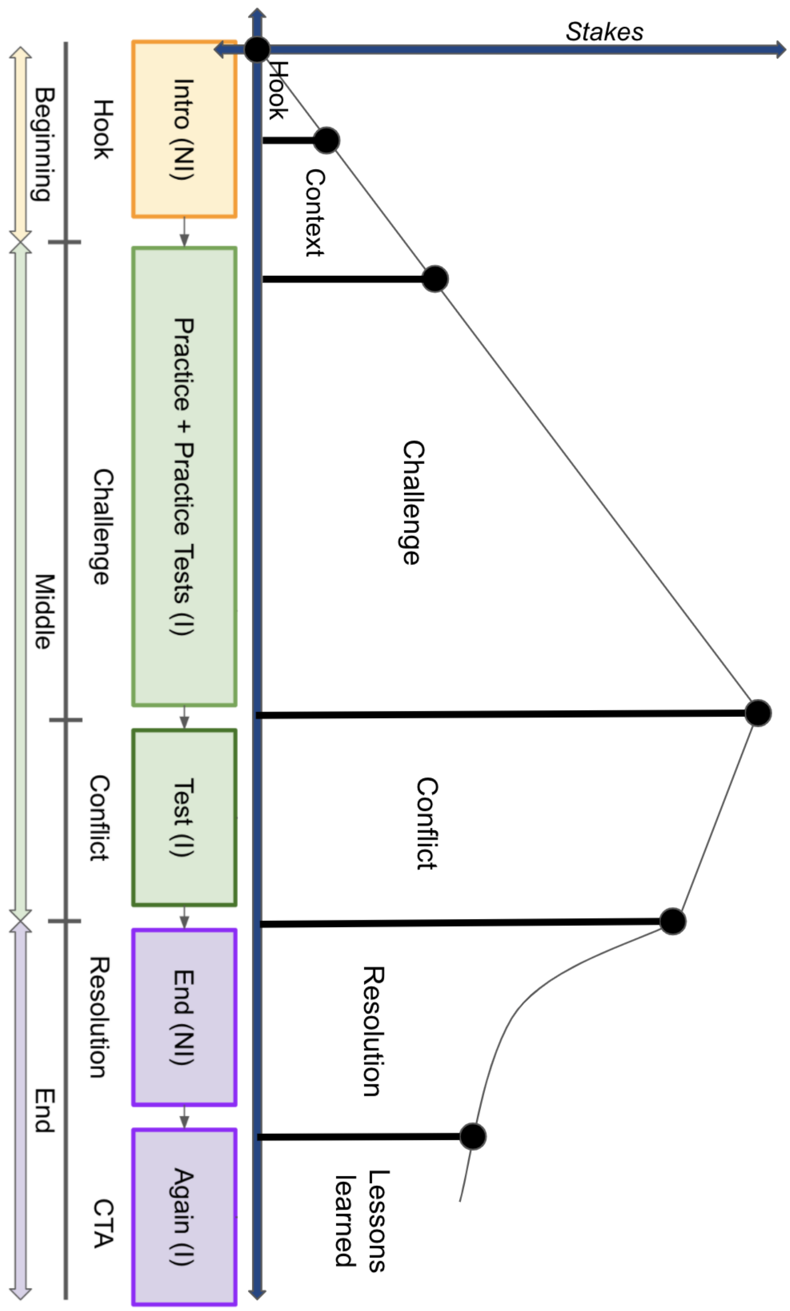

Figure 6.5. Storyfication Framework with the Storytelling Graph.

2. **Middle**: The middle section of the story narrative consists of the significant training section. Finally, the user is introduced to an interactive (I) story plot. It consists of challenge and conflict.
3. **Challenge**: The challenge is the story section, where the user experiences the practice and practice tests for a task that needs to be trained in the form of one or many interactive story plots. In this section, the user is trained in the form of a story and asked to finish a practice task to get hands-on experience. The user does tasks for which they make choices: If they make right choices and performs task efficiently, their stakes will reduce and challenge increases. Conversely, for bad choices, their stakes increase.
4. **Conflict**: The conflict is the story section, where the abilities and learnings of the user are put to the test. The performance of the user affects the next section of the story. This is an interactive story plot. This can be compared to the climax of the story.
5. **End**: This is the third and last section of the storyfication framework. It consists of resolution and Call to Action (CTA).
6. **Resolution**: The resolution section is a non-interactive story plot where the user is shown the result of their performance in the form of a story ends. This story will change based on the user's performance of the task in the conflict section. (Figure 6.4)
7. **CTA**: The call to action section gives an option to the user through an interactive story plot to again enter the challenge or conflict story plots to get re-training if they wish to.

6.4 Storyfication Benefits on Training

- It increases neural coupling that enables the listener to convert the ideas presented in the story into his/her own ideas and experiences. Stephens et al. [112] connected the extent of neural coupling to a quantitative measure of story comprehension and found that the greater the anticipatory interactive story - listener coupling, the greater the understanding.
- In the process of memory formation, the episodic buffer is responsible for storing the information from short-term to long-term memory. The interactive story will help bind information faster [102]
- There are benefits of storyfication on human emotions. There is the release of dopamine when experiencing an emotionally charged event.
- Cortex Activity - Storyfication makes the user engage the motor cortex, sensory cortex, and frontal cortex when processing interactive stories.
- Higher Engagement and Focus - It makes it easier to remember information with greater accuracy.

CHAPTER 7

vIIS - VOCATIONAL INTERACTIVE IMMERSIVE STORYTELLING SYSTEM

This chapter is partly based on the following publications

- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2021. Designing a Vocational Immersive Storytelling Training and Support System to Evaluate Impact on Working and Episodic Memory. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA*

When a new worker joins the workforce, training is given in either active or passive ways. Active training is when a mentor is assigned to the new worker, and the new skill or job is taught. The advantage of this training method is that the mentor provides instant feedback and offers their experience that enhances the learning experience. The other method is passive, where an expensive training tool is used to train a new skill to the worker. It saves much time for other workers assigned as mentors, but this method does not constantly provide feedback. Thus, the passive method is not engaging as well.

This chapter presents a framework as discussed in [106] that uses Interactive Immersive Storytelling to train a new skill and assess the worker's performance. Furthermore, I implemented a system based on the vIIS framework to test its performance against desktop-based 2D system training. The main objective of this study to improve the skills learned in vIS by Interactivity and Storyfication. The significant advantage of this vIIS system is that it provides constant feedback in an engaging, immersive augmented reality environment and has better memory retention and recall of the trained task.

Our hypothesis for this study is that vIIS performs better than desktop 2D training systems for both working and episodic memory tasks. The research questions that will be answered in this chapter are *RQ3 - How does interactivity help in the learning process in vIS? and RQ4 - Does storyfication enhance user engagement in vIIS?*

7.1 vIIS Framework

In this section, the vIIS Framework is presented (Figure 7.1) that defines the architecture of the vIIS system built later for the user study. This framework consists three main HCI components which are the human component *User*, the cyber component *Storyfication* and the *Feedback* component. The AR environment encapsulates the Storyfication component that comprises a non-interactive story plot, an interactive story plot, a task repository, and a feedback component. All the components are described in detail below. This framework is designed to create an interactive, immersive storytelling system for vocational training. vIIS Framework can develop a system to impart training and assess the various performance metrics from measuring cognitive load to measuring recall rate.

7.1.1 AR Environment

The Augmented Environment is the main component of the vIIS framework which encapsulates all the other components. Augmented Reality is an immersive medium, and because of this, the whole training and learning experience can be

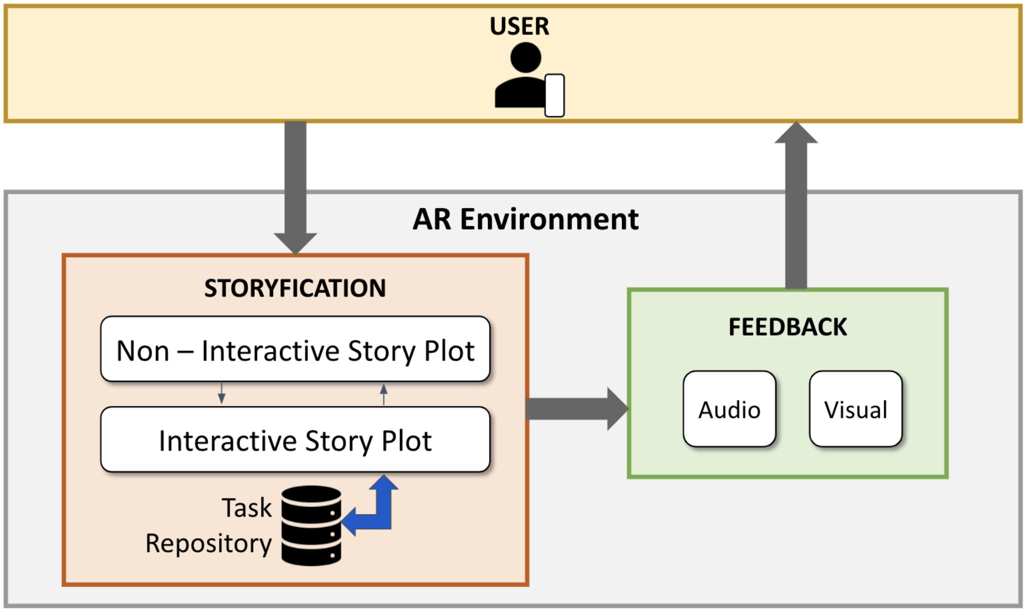

Figure 7.1. vIIS Framework.

done in this immersive AR environment. The user is immersed in the AR environment completely and experiences the story like a real-life scenario. This aids better engagement. There are two types of Augmented Reality experiences, mobile/tablet-based, and headset-based. This framework supports both kinds of AR experiences. In vIIS system implementation, a handheld mobile AR device was used.

7.1.2 User

The user is the human component in this framework. The assumption is that the user will have little to no knowledge of the skill being taught using this framework. Another assumption is that the user will neither have any disability nor visual impairment. This framework requires the user to use virtual reality head-mounted displays and joystick as an interactive tool with the VR environment.

7.1.3 Storyfication

The Storyfication component is the heart of the system. This immersive interactive story comprises sub-components such as a non-interactive story plot and one or multiple interactive story plots. The story is a 360-degree animated video depicting a real-life scenario of any chosen vocation, which has an engaging narrative and consists of multiple story plots. The story narrative is developed to provide a real-world perspective into the actual training in the field. For example, to teach a worker how to use a tool, e.g., a vernier caliper, the narrative could be of a crisis-like situation on the field where a worker is shown teaching the use of vernier caliper to his partner. When viewing the narrative in an immersive environment, the user gets a first-hand experience into the actual training. Thus, the 360-degree environment and the immersion both play a vital role in the training.

The training narrative could be designed so that the user feels motivated to interact with the environment to gain loyalty points. The user interaction could be focused on learning the assigned task by breaking it up into lots of smaller sub-tasks, where performing the interaction plays a crucial role in learning a sub-task. For example, to learn how to use the vernier caliper, the story could break the learning process into chunks of sub-tasks. One sub-task could be to caliber the vernier caliper before starting any measurement. Here, by motivating the user to perform the sub-task, he could be given loyalty points. This way, the user feels more engaged while being trained. The story and interaction with the system for training are combined in the Storyfication component.

7.1.3.1 Non-Interactive Story Plot

The non-interactive story plot is a narrative that depicts a scenario that introduces the user to the environment, gives an overview of the problem and task that needs to be done. It is like a training phase which is a view-only training mode (non-interactive). It resembles the traditional method of training. The training to be provided is embedded in a storytelling narrative, which can be modified through a simple graphical user interface. This story plot is non-interactive because I want the user to be immersed in the experience without any distraction. Immersive augmented reality is a new training medium, and it takes some time for the user to get accustomed to it. The non-interactive story plot will familiarize the user with the task without adding any cognitive load of doing any activity at this point in the learning process.

7.1.3.2 Interactive Story Plot

There is only one non-interactive story plot; the story can have any number of interactive story plots. These plots are interactive, where the user can perform a task to help the story narrative move forward. These interactive story plots not only provide more intense training but also assess the performance of the user. In contrast to the non-interactive story plot, where the user only views the training narrative, the user also interacts within the immersive environment to get hands-on training on the learned task. The tasks are selected from the task repository, and storyfication enriches the user's experience.

7.1.3.3 Task Repository

The task repository may consist of one or many tasks which can be added as an interactive story plot. This story plot narrative is designed to involve the user as part of the narrative. When the story reaches a point where after demonstrating how to perform a sub-task, the story could turn towards the user and ask her to perform the sub-task; this way, the user is forced to interact with moving the narrative forward. Multiple tasks can be added to the story as interactive story plots.

7.1.4 Feedback Component

The feedback component is integrated with the environment, which continuously analyzes the user's performance and reports the metrics on a graphical user interface in audio, visual, or haptic feedback. For example, the audio feedback could be from a virtual avatar in the story; the visual feedback could be displayed on the user interface of the head-mounted display or a handheld device, depending on the design choices during this framework implementation. To supplement the training, the user could also be required to perform an off-line evaluation of the learned task. Then, manual comparison of the off-line evaluation can be compared against the performance of immersive evaluation, and the narrative can be adjusted accordingly.

7.2 System Design

The vIIS Framework was used to implement a training system for the user study. In order to implement all the components of the framework, several design decisions were taken. In this section, story design, immersive environment design, and 2D desktop system design are described.

Figure 7.2. AR Environment Avatars as Character Lily (left) and Mr. Roy (right).

7.2.1 Story Design

The Storyfication component requires a story that has a non-interactive story plot and one or many interactive story plots. Hence, story design is crucial and the backbone of this training system. The story should contain main plot, which is the theme or the main storyline, characters, an environment where the story incidents are taking place, a problem or an inciting incident that makes the user emotionally invested in the story, tasks for training, training interactive story plots that help user train with the immersive system and test interactive story plots that help user test their newly learned skills and receive feedback from the system. Each one of the components of a story is explained in detail as follows:

Characters: The protagonist of the story is the user using the system. This is a first-person story. The two main characters of the story are Lily, the user's friend, and a factory worker, and Mr. Roy, the factory manager, as seen in Figure 7.2.

environment: The selected environment is a wooden toy factory. A toy manufacturing factory was selected to resemble a toy's assembly process, which requires both episodic and working memory.

Plot / Main Storyline: Lily, the friend, takes the protagonist, in this case, the user, to the factory for the job and introduces the user to Mr. Roy, the factory manager. Mr. Roy explains the overview of the factory. The factory creates environment-friendly wooden toys for the world's biggest toy store. Every year they organize a big fair where children love wooden toys. Mr. Roy informs Lily and the user about the new problem they are facing. Mr. Roy offers the user a trainee position and asks them to start the training to learn and contribute to the factory quickly. Friend Lily trains the task to the user step by step and provides feedback. Mr. Roy oversees the final test. The success/failure of the factory and the user's job depends on the test result.

Problem / Inciting incident: The problem is that they need to increase production to meet the tight deadline or else a new plastic toy company will beat them to market, and the order from the world's biggest toy store will go away.

Tasks: There are two tasks - Toy assembly (Episodic Memory task) and Toy packaging (Working Memory task). The tasks were inspired by NIH's object sorting and picture sequence tasks, respectively.

Toy assembly task: This is a picture sequence task. There are three sequences in total, with sequences 1 & 2 having five objects and sequence 3 having ten objects. This will be followed by a test of all 20 sequences (Seq 1, 2 & 3).

Sequence 1 - How to use compressor machine - 5 steps (Figure 7.3)

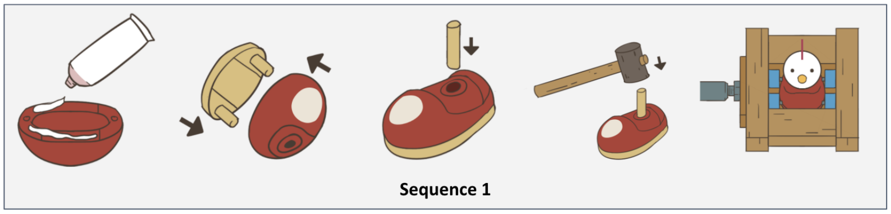

Figure 7.3. Toy assembly task sequence #1 (How to use compressor machine - 5 steps).

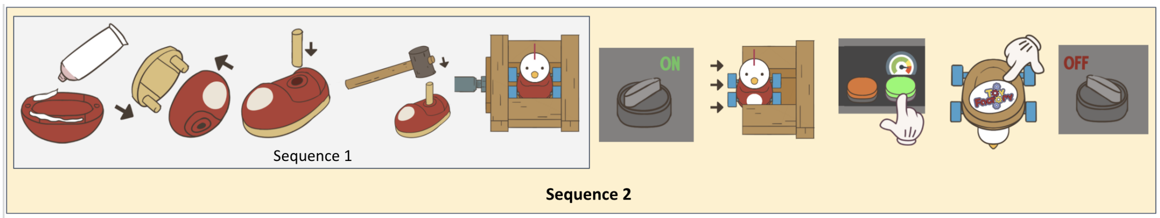

Figure 7.4. Toy assembly task sequence #2 (How to assemble toys - 10 steps including sequence 1).

1. Switch on the machine
2. Keep the toy in the machine
3. Select compressor pressure
4. Add company label sticker
5. Switch off the machine

Sequence 2 - How to assemble toys - 10 steps including sequence 1 (Figure 7.4)

1. Add glue on the base
2. Press the toy body on the base
3. Place a nail in the hole
4. Hammer the nail
5. Compress the toy in the machine
6. Switch on the machine

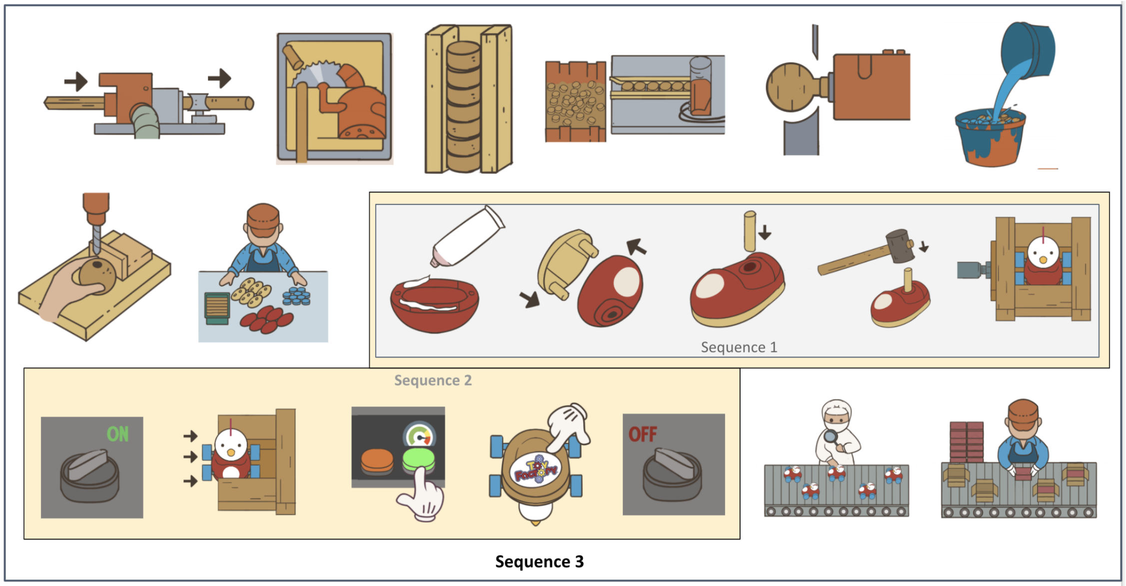

Figure 7.5. Toy assembly task sequence #2 (How to work at toy factory - 20 steps including sequence 1,2).

7. Keep the toy in the machine
8. Select compressor pressure
9. Add company label sticker
10. Switch of the machine

Sequence 3 - How to work at toy factory - 20 steps including sequence 1,2 (Figure 7.5)

1. Feed the lumber in machine to turn them into rods
2. Cutting machine cuts the rods different lengths
3. Stack the cut pieces in feeder tube
4. Feeder tube drops cut pieces on a router table where they are separated
5. Filing machines turns wooden blocks into different shapes
6. Non toxic paints are poured to color the blocks
7. Worker makes hole in every block
8. Worker assembles the blocks to make them a toy

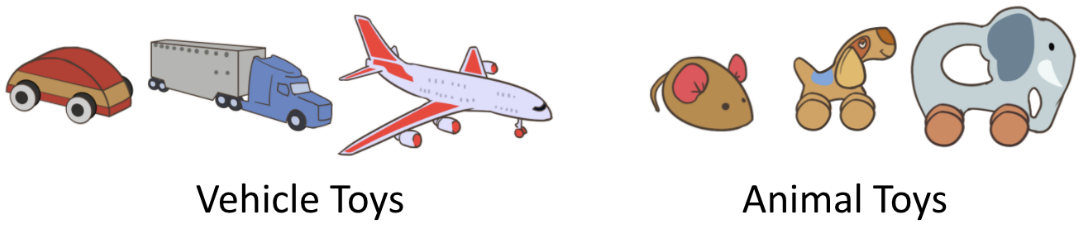

Figure 7.6. Vehicle and Animal Toys for toy packaging task.

9. Add glue on base
10. Press the toy body on the base
11. Place a nail in the hole
12. Hammer the nail
13. Compress the toy in the machine
14. Switch on the machine
15. Keep the toy in the machine
16. Select compressor pressure
17. Add company label sticker
18. Switch off the machine
19. Inspect the toy for perfection
20. Pack the toy for shipment

Toy packaging task: This is an object sorting task (Figure 7.6). The user needs to sort the objects in a particular order to get them ready for toy packaging in a particular order. The user is shown 3 objects (e.g., 3 types of vehicle toys) to sort them in size order. Then the user is shown 3 more objects of another type (e.g., 3 types of animal toys) which they need to sort them in size order, first vehicles and then animals. Once this training task is complete, there is an object sorting test in the end.

Training interactive story plots: For the toy assembly task, the user needs to learn sequence one in the interactive training story plot, perform a training task for sequence one, then learn sequence two, which consist of sequence one and a set of 5 new pictures, and perform a training task for sequences one and two together. After this, the user learns sequence three, consisting of all sequences one and two and ten new pictures. For the toy packaging task, there are two stages. The first stage is sorting one type of toys, and the second stage is sorting two types of toys in size order. First, the user needs to sort one type of toy, such as three vehicle toys, in size order. Then the user needs to sort six toys of both kinds – vehicle and animal toys.

Test interactive story: For the toy assembly task, the user interacts with the interactive test story and performs sequence three with system feedback. For the toy packaging task, the user interacts with the test interactive story and sorts 6 toys of both vehicle and animal toys for a particular set time.

feedback: The system generated feedback when the user interacted with the story to complete a task. The feedback was given in the form of Lily's comment on the user's action. They comprised positive and motivating comments such as 'Good job', 'Excellent, let us make it challenging', 'Try again with more focus', 'Let us reduce the complexity. Sort few toys'

7.2.2 Immersive Environment AR Design

In order to design the immersive AR environment, several artifacts were designed to achieve the final system features. They consist of sound design (dialogues), storyboarding, interaction, feedback design, and user interface design. These artifacts played a crucial role in creating an overall engaging, interactive, and immersive story experience. These artifacts are explained as follows:

7.2.2.1 Sound Design

The dialogue by avatars presents the story narratives. The dialogues were designed to make a simple yet engaging experience. The dialogues were created for both non-interactive story plots and interactive story plots. These are the dialogues and script of the entire story. The voiceovers were recorded for each character and used as original audio in the AR environment.

Script of Dialogues

Lily: So you want a job at the Toy Factory I work in. Sure, I can refer you and introduce you to the factory manager.

Lily: This toy factory makes eco-friendly wooden toys. Meet Mr. Roy; she is the factory manager. Mr. Roy, please meet my friend who wants a job as a factory worker and is excited to learn more.

Mr. Roy: Hello, nice to meet you. Excuse me, I'm in a rush. We need to ramp up the production due to some changes. Lily, we have some serious competition. The toy shop who used to buy the toys, has an offer from another factory that makes plastic toys. We are worried. We need to make some animal and vehicle toys and ship them in boxes they have sent us as soon as possible.

Hey, if you want to work here, this is the perfect time. We need more workers. Why don't you start the training today and start working as soon as possible? If you do well, the job is yours.

Lily: Congratulations, you are a trainee now. There are two types of tasks here: Assembly and Packaging. Let's begin your training so that you can contribute to the production.

Lily starts training with the toy assembly.

Lily: Let's get you started with assembly task. First, let me show you how to use a compressor machine. The compressor machine compresses the toys to fix them in their shape. To finish the task, look at the sequence appearing on the screen. Then drag and drop the images in the correct order.

Lily:

Switch on the machine

Keep the toy in the machine

Select compressor pressure

Add company label sticker

Switch off the machine

Lily: This is how you use a compressor machine. Why don't you try it.

The user tries the sequence by pressing buttons on the desktop/mobile screen.

Lily: Great job. Now let's assemble the toys along with using the compressor machine. Assembling of toys requires joining different parts of the toys together. Let's begin.

Lily:

Add glue on the base

Press the toy body on the base

Place a nail in the hole

Hammer the nail

Compress the toy in the machine

Lily: This is how you assemble the toys and use the compressor machine. Why don't you try it?

The user tries the sequence by pressing buttons on the desktop/mobile screen.

Lily: Now you are ready to learn the whole process on how to make the toys in the Toy Factory. This process involves everything from cutting the woods, giving shape to the woods, painting the wooden parts, assembling, and making it ready for packaging. Let's begin.

Lily:

Feed the lumber in machine to turn them into wooden rods

Cutting machine cuts the rods different lengths

Stack the cut wooden pieces in feeder tube

Feeder tube drops cut wooden pieces on a router table where they are separated

Filing machines turns wooden blocks into different shapes

Non toxic paints are poured to color the blocks

Make a hole in every block

Assemble the blocks to make them into a toy

Inspect the toy for perfection

Send it to the packing station

Lily: This is the entire process to make toys. Why don't you try it.

The user tries the sequence by pressing buttons on the desktop/mobile screen.

Lily: Great job. Now we have all the toys that need the right packing.

Lily then takes the user to the toy packaging area.

Lily: Welcome to the packaging area. Now we have all the toys that need the right packing. We have shape defined boxes. So we need to Sort the toys in size order from smallest to largest to correctly fit them in the box. Let me show you how it's done. You are going to see vehicle toys one at a time on the screen. After each set of picture, you will see a blank screen. When you see the blank screen, select the toys in size order from smallest to largest. For example, if you see a truck, a car and a plane, you would click on the box containing a car, a truck, and a plane. This is the correct size order, car being the smallest and plane being the largest. Why don't you try sorting the vehicle toys. Select the toys in size order from smallest to largest toy.
Lily: Let's start the packaging of our bigger boxes with more toys. This time you'll see vehicle and animal toys one at a time on the screen. You need to sort the vehicle toys first, animal toys second in size order from smallest to largest. It is important to pay attention to the size of the object on the screen when selecting the toys in size order. For example, if you see an elephant, a truck, a duck, a car, a plane, and a sheep, you would click on the box containing car, truck, plane and then duck, sheep and elephant. This is the correct size order, vehicle toys first and then the animal toys. car being the smallest vehicle and plane being the largest vehicle toy and then duck being the smallest animal toy an elephant being the largest animal toy. Why don't you try sorting the vehicle and animal toys. Select the toys in size order from smallest to largest toy.

Lily: Now you are ready for the test. Let's see how many boxes you can help us pack in 10 minutes. Your work will help decide the fate of our packaging goal. Select the toys in size order from smallest to largest toy.

7.2.2.2 Feedback dialogue

The story ends with system feedback. The success or failure of the tasks decided the positive or negative end of the story, respectively.

7.2.2.3 Storyboarding

Storyboarding is designing the flow of scenes in a story. The storyboarding was done to decide the placement of characters, objects, and transitions of scenes (Figure 7.7). (a) shows the design of a starting scene where Lily, the friend avatar introduces the toy factory environment to the user. (b) and (c) is the environment design for toy packaging tasks. (d) and (e) is the alternative success and failure ending scenarios, respectively.

7.2.2.4 Feedback design

The feedback was given after every step the user took to interact with the system to complete a task. The feedback was designed to be positive, encouraging, and motivating to stay engaged in the immersive story.

7.2.2.5 User Interface Design Decisions

: A lot of design decisions were made to create a suitable fictional story. I started with storyboarding and made multiple iterations over the story's design to

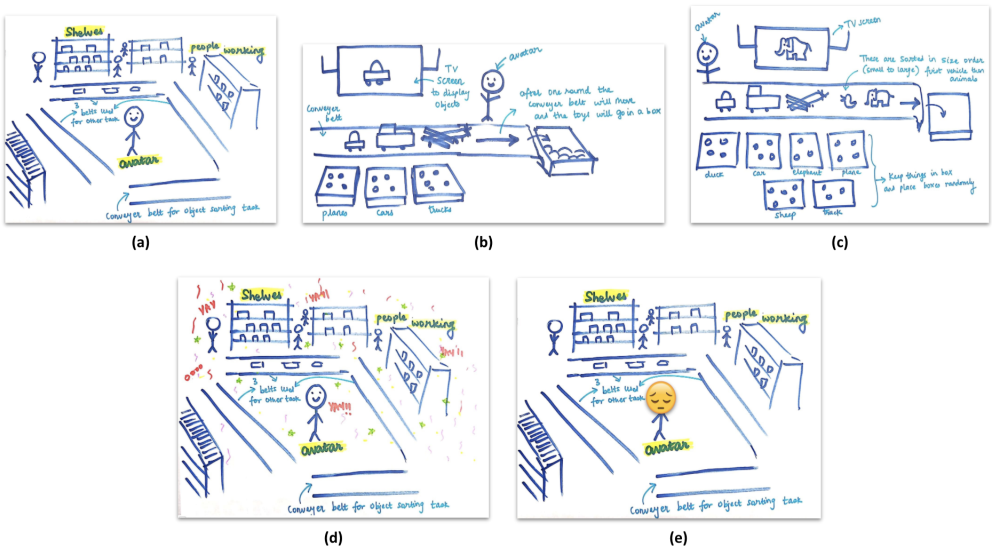

Figure 7.7. Storyboarding to Design AR Environment.

Table 7.1. Toy Assembly Task Feedback Dialogues:

User Input	System Feedback	Dialogue
Correct	hooray	Good job
Wrong	Oh noooo, hawww sounds	You missed a step. Try again

Table 7.2. Toy Packaging Task Feedback Dialogues:

User Input	System Feedback	Dialogue
Correct once, correct twice in a row	hooray	Good job
Correct max time for that level	Celebration music, hoorah cheer	Excellent, let's make it challenging
Wrong twice in a row	Oh noooo, hawww sounds	Try again with more focus
Wrong more than two times	Red alert alarm activate panic more	Let's reduce the complexity. Sort few toys

Table 7.3. End of Story System Feedback Dialogue

System Feedback	Dialogue
Happy cheer in the factory - celebration:	Success -We did it!! Your work saved us
Sadness	Failure - We missed our mark this time. We will do it next time. Would you like to do your training or test again?

create a story that delivers the training information in the right way, impacts the user's working and episodic memory, and elicits the right emotions of the user to aid in the long-term recall of the training content. Design decisions taken while designing the system are described below.

Design Decision #1 – Story format: The format of a story plays a huge role in how well the viewer stays connected and engaged with the story content. In order to keep the story length short and avoid adding complications, we chose the most common form of narrative fiction, a *three-act structure*, which divides the story into three parts:

1. *The Setup:* The user (protagonist) is introduced to the toy factory manager, tasks, and the problem, which gives them a purpose to participate in the immersive story.
2. *The Confrontation:* Commonly referred to as the story's hook, it was critical for us to pick the right event to elicit the right emotion of the viewer. Usually triggered by an onset of an unexpected event, termed as inciting incident action, the protagonist attempts to resolve the problem by learning a new skill(s), often referred to as character development. The factory manager informs the user about the potential threat to the toy factory and how their input can make a considerable difference to the outcome.

3. *The Resolution:* Part of the story that features the resolution preceded by the story's climax. All the tests given by the user can be considered in the climax of the story. The result of the tasks decides the success or failure of the story.

Design Decision #2 – Visual Perspective: In immersive environments, the two main types of perspectives available are first-person perspective (1PP), in which the camera is in the viewer's eye, and third-person perspective (3PP), in which the camera is at an adjustable distance and angle of view. The decision to choose between 1PP and 3PP was a crucial one. From initial vIS studies, we found that the users prefer 3PP as it makes it easy to perform spatial navigation in the immersive environment. Furthermore, on testing the 3PP design prototype, users said it gave them a sense of control and safety when introduced to a new environment. vIIS training system was designed for handheld mobile AR devices. Therefore, it was important to give the user a sense of control of their environment and AR objects in the immersive environments.

Design Decision #3 – AR Object placement: The object placement is designed to allow the viewer to easily focus on the main components of the story and have the freedom to look around the surrounding environment in the viewer's field of vision through a handheld mobile device. Once the user starts the immersive experience, all the AR objects are placed in the user's environment and fixed. They do not require move at all. The placement of the AR objects depends on the height of the user and the texture of the surface. The lighting conditions are decided based on these two factors. The goal of this system to training the user by interactivity. The interaction was design to be fluid, responsive with any lags, and timely audio feedback. As the user is free to move in the environment, it was essential to design an experience that focuses the viewer's attention on the story's primary activities. In order to reduce the lag generated by the heavy rendering process, non-necessary objects were removed from the system, such as extra workers, different objects on the factory floor, and decorative objects. This also helped the user to focus on objects that were only important for the task.

Design Decision #4 – Sound: An immersive story is impacted less without a good sound design. Sound plays a significant role in how the user interacts, engages, and consumes the information from a story. Salselas et al. [99] reviewed the literature on the role of sound in immersive storytelling. They found that a good sound design modulates a viewer's attention in a way that allows for an immersive user experience and allows the viewer to deduce that a narrative is being followed. The sound is added only in dialogues to maintain the concentration levels of the user only on the task and the story. Excessive sounds in a handheld mobile AR device may confuse the user and may distract them.

Design Decision #5 – Embedding Training Material: The tasks were chosen to impact the working and episodic memory. Adding the training material for toy assembly and packaging in the story was critical to allow for long-term recall and improving attention. However, we wanted to avoid creating the story to make it look like a glorified instructional video or creating too informal of a storyline that the viewer would not focus on the training material. One of the characters is used as a helping avatar that provides instructions and feedback by taking the story narrative forward to strike the right balance.

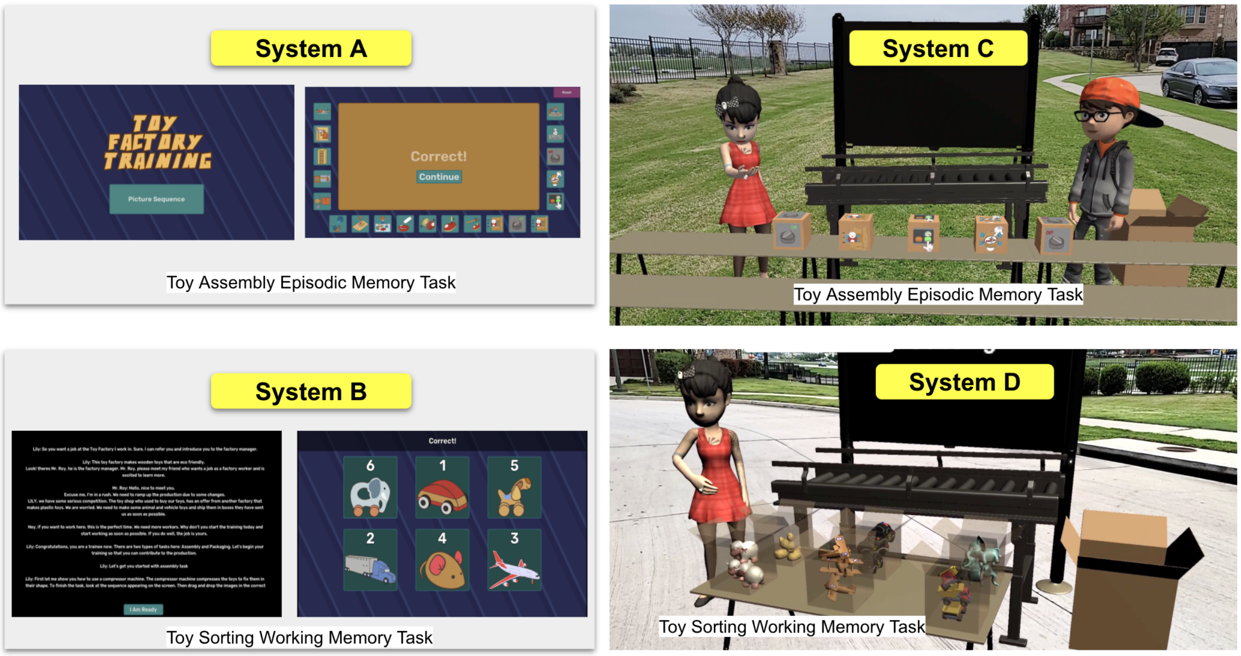

Figure 7.8. System A, B, C, D.

7.2.3 Desktop Game Design

The 2D desktop system was designed using the same story, dialogues, and tasks to reduce variable components. The only difference between the 2D desktop system and the immersive AR environment is the medium – 2D vs. immersive 3D systems. System A and D show the non-interactive story plots of the 2D desktop system. (b) and (c) shows the toy assembly picture sequence task for episodic memory. System E and System F show the toy packaging object sorting task for working memory.

7.3 Study Design

In order to examine whether the immersive platform is better than existing desktop-based training systems, two training systems were designed for each type of task, keeping the tasks and the storyline the same (Figure 7.8).

2D Desktop System for Episodic Memory Task (System A): The first system shown is a web-browser-based 2D Desktop system that can be played on the computer. First, the user will practice the Toy assembly episodic memory task. Then, after the practice session, the user will give a test. The test will be the same two tasks, but no feedback or support would be given from the system.

2D Desktop System for Working Memory Task (System B): The second system shown is a web-browser-based 2D desktop system that can be played on the computer. The user would be shown a story where they will be walked through a packaging scenario. The scenario is that the user is a factory trainee, and they need to start training. The user will practice toy sorting working memory task. After the practice session, the user will give a test. The test will be the same task.

vIIS System for Episodic Memory Task (System C): The third system shown is Augmented Reality mobile-browser based that can be played on the user's mobile phone. The user will download the app and begin the user study. The user would be shown an immersive story with sound and 3D objects in their space where they will be walked through a scenario. The scenario is that the user is a factory trainee, and they need to start training. The user will practice the toy assembly (picture sequence) episodic memory task. After the practice session, the user will give a test. The test will be the same task.

vIIS System Working Memory Task (System D): The fourth system shown is Augmented Reality mobile-browser based that can be played on the user's mobile phone. The user will download the app and begin the user study. The user would be shown an immersive story with sound and 3d objects in their space to walk through a scenario. The scenario is that the user needs to sort toys for packaging. The user will practice toy sorting task. After the practice session, the user will give a test. The test will be the same task.

7.3.1 Study Procedure

In order to empirically evaluate the above research questions, we developed a between-subjects experiment in which participants were allocated, in round-robin, to one of the two training methods for working memory and episodic memory user study. The two systems that are compared in the study are the following:

vIIS System (System C and D): In this method, the participants were given an AR android app. The immersive story was shown on the AR mobile app. The users were asked to conduct the user study in a quiet location with a spacious floor to view the AR objects through the app.

2D Desktop System (System A and B) : In the approach, the participants were given a 2D interactive training system hosted on a web server. Video with the same storytelling components as the immersive system, which explained the story and the tasks.

The procedure followed is as follows.

1. The participants were asked to read through this Informed Consent and email the Principal investigator if they had any questions; then make their choice about whether to participate.
2. They were randomly selected for one of the four systems.
3. Training Session: They were asked to use the system and practice the tasks. In the practice session, the system taught them how to complete the task and feedback for their inputs.

4. Test Session: After completing the practice sessions, the participants were asked to complete the task again.
5. They were asked to fill out a questionnaire. The questionnaire contained questions asking about age, gender, how will the user rate their experience playing the game, how will they rate their memory completing their, did they enjoy, was the task effective, was there any discomfort, and an open-ended comment they might have.
6. They were asked to retake a test session one week later.
7. They were asked to fill out a questionnaire again; this was the same as the previous questionnaire.

To measure the learning and recall of these methods, the user study was divided into two phases with a gap of seven days between both phases (Figure 7.9 and 7.10).

7.3.1.1 Episodic Memory Task

Day 1 Training session: Participants were presented with an Informed consent form. After giving consent, participants were assigned to one of the episodic memory training methods where they interacted with the assigned system and trained. Once the training for the task with all three sequences was complete, they were given a test of sequence three that was a part of the story. After using their respective systems, in the end, the users were asked to fill out a questionnaire. Their answers, along with the SUS scale responses, were then collected.

Day 7 Test Session (seven days after a training session): Participants were sent a reminder to use the system after seven days. First, they were asked to use the system and only give the test of sequence 3. Then, they were shown the story and asked to perform sequence three of the toy assembly task.

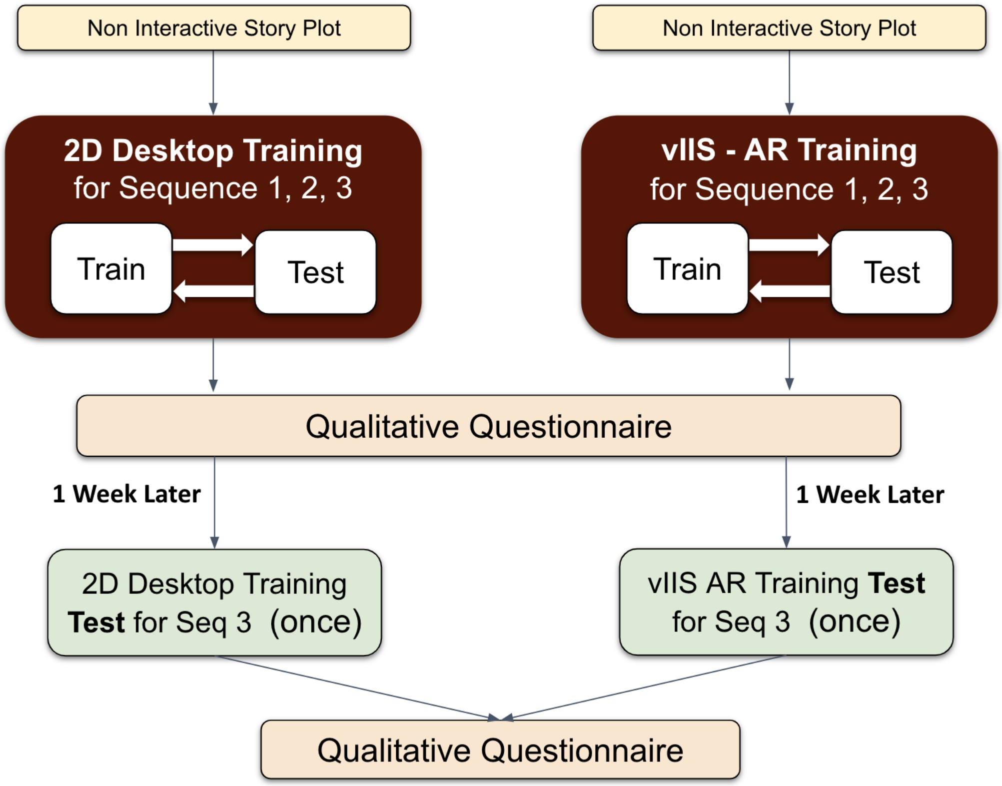

Figure 7.9. vIIS Episodic Memory Task Study Procedure.

7.3.1.2 Working Memory Task

Day 1 Training session: Participants were presented with an Informed consent form. After giving consent, participants were assigned to one of the working memory training methods to interact with the assigned system and trained. Once the toy sorting task training with all two types of toys (6 toys) was complete, they were given a test of 6 toys that were a part of the story. After using their respective systems, in the end, the users were asked to fill out a questionnaire. Their answers, along with the SUS scale responses, were then collected.

Day 7 Test Session (seven days after a training session): Participants were sent a reminder to use the system after seven days. They were asked to use the system

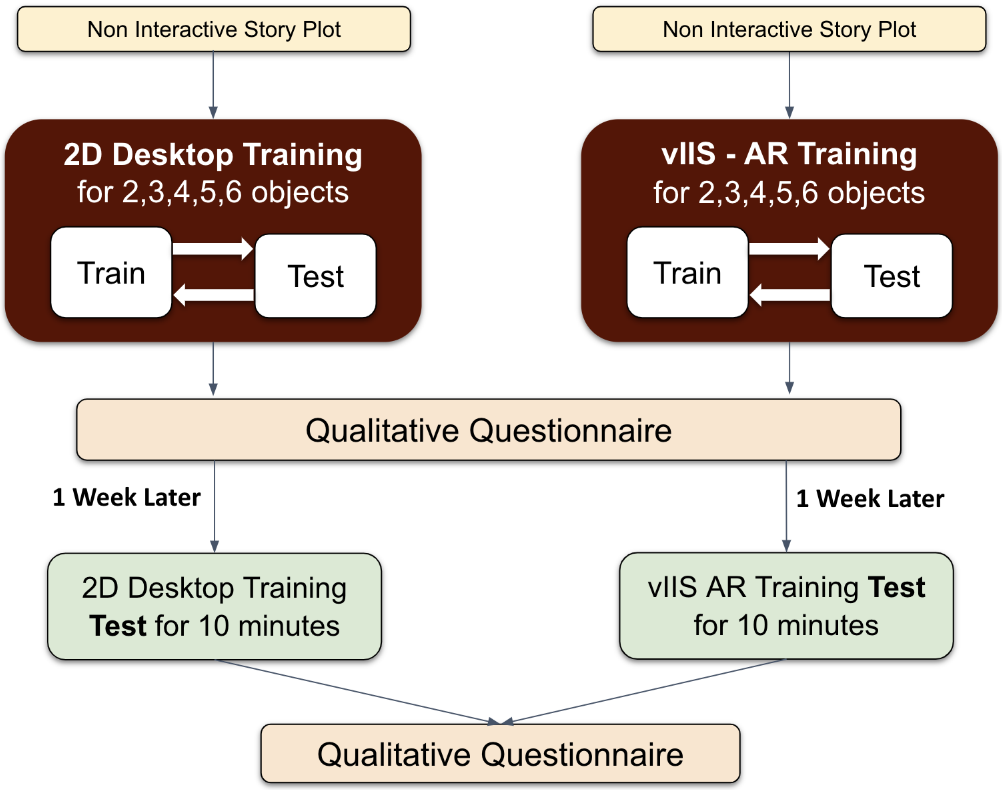

Figure 7.10. vIIS Working Memory Task Study Procedure.

and only give the test. They were shown the story and were asked to sort six toys for 10 minutes.

7.3.2 Participants

The study was conducted online and was approved by the university's Institutional Review Board (IRB). The study hosted and recruited participants through the Amazon Mechanical Turk website [113]. 138 participants were selected for this study, 69 participants were recruited for each task. The participants from the age group 18 to 40 were required with good sight and no disability.

7.3.3 Data Collection

For each of the above study groups, the following data was collected:

1. Task performance was captured by measuring the time taken and the number of mistakes (task accuracy). Time is taken to complete each task
2. Time taken to complete the task
3. User's score for each level in the task
4. How many tasks the user completed successfully at each level
5. Time spent on each level of the task
6. Survey data
7. Satisfaction is an index used to qualify the user's feeling of adequacy with a given situation. The overall satisfaction was captured after each condition for each participant by self-assessment on a 5-point scale (range 0 to 4)

7.3.4 Duration

This study was remote and could be completed any time based on the participant's time availability. It would take about two sessions, the first being 45-60 minutes and the second 15 minutes long. The second session was conducted one week after the participant had participated in the first session.

7.4 Results

We start with reporting the demographic information of our participant pool. As already pointed out earlier, the purpose of the usability study is to assess the effectiveness and long-term recall rate of *vIIS* and compare it against a Desktop Storytelling System. First, a one-way analysis of variance (ANOVA) to test for statistically significant differences between the two different training methods was conducted.

Then turkey post hoc test to reveal where does the significance lie was conducted. Wherever possible, the data analyzed using box-and-whisker plot diagrams were also depicted.

7.4.1 Demographics

Our usability study was hosted as Human Intelligence Task on Amazon Mechanical Turk. We enrolled 138 participants in the usability study. 69 random participants were assigned to the Episodic Memory Task, and the remaining 69 participants were assigned to Working Memory Task. Among the participants who reported their age, the age ranges varied from 18 to 53, with a mean age of 37. In addition, 64% of the participants identified their gender as male, 33% identified as female, and the rest preferred not to answer.

7.4.2 Training Time

Training time is measured as the time taken by a participant to complete the training session for the assigned task. Figure 7.11 shows the training time comparison for the Episodic Memory Task between the Desktop training system and vIIS. The average training time for participants in the desktop system was 322 seconds with a standard deviation of 35 seconds. In contrast, the training time for participants in vIIS was an average of 348 seconds and a standard deviation of 27 seconds. We observed a statistically significant difference in the mean training time between both systems using a one-way ANOVA test, p=0.0023. Table 4.4.1.2 shows the summary of comparison of training time.

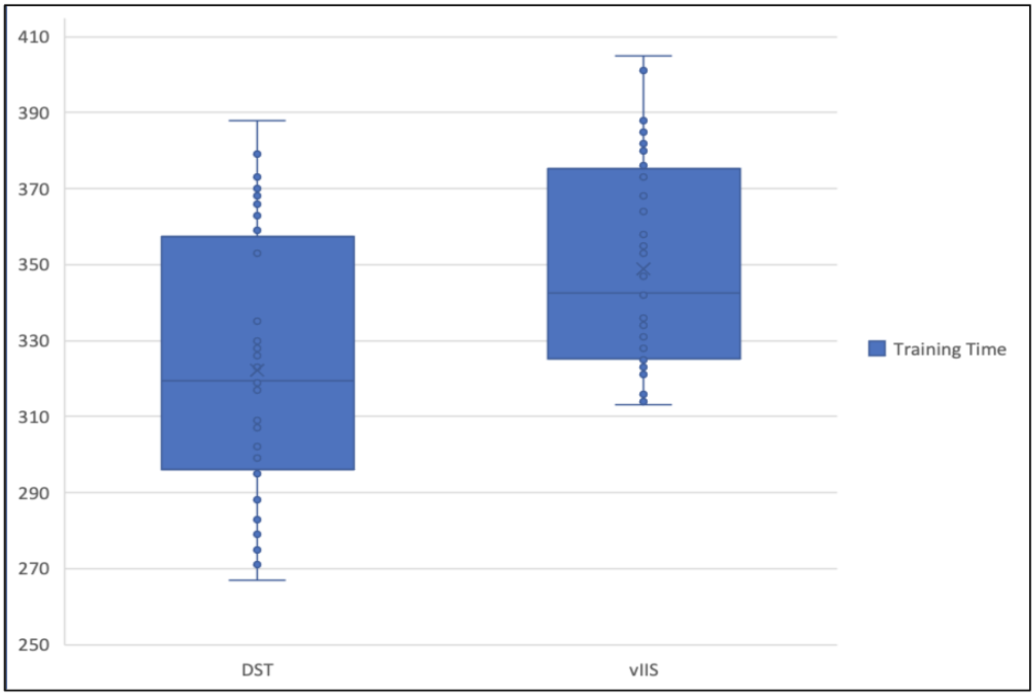

Figure 7.11. Training time comparison for Episodic Memory Task between Desktop Storytelling (DST) and vIIS (in seconds).

7.4.3 Recall Time

Recall time is measured as the total time taken to recall the training sequences in the episodic memory task. Figure 7.12 shows the recall time comparison for Episodic Memory Task for Desktop Storytelling (DST) and vIIS system. In the figure, Recall time 1 is the time taken by participants to recall the sequences immediately after training. Recall time 2 is the time to recall the learned sequences seven days later.

Table 7.4. Training time stats for Episodic Memory Task (in seconds)

Training Method	**Mean**	**Median**	**Std Dev**
DST	322.28	319	35.19
vIIS	348.83	342	27.14

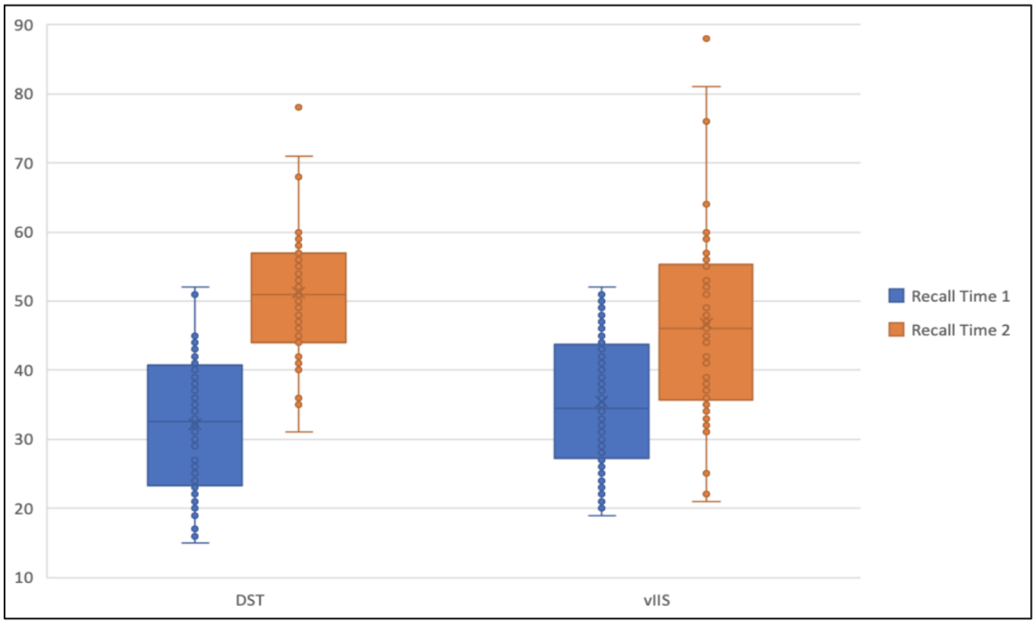

Figure 7.12. Recall time comparison for Episodic Memory Task between DST and vIIS (in seconds).

The recall time measured immediately after training was an average of 32 seconds for DST compared to 35 seconds for vIIS. When participants recalled the sequences seven days later, the average recall time for DST was 51 seconds compared to 46 seconds to vIIS. The table shows the detailed statistics of recall time measured for DST and vIIS systems. Participants in the DST group made 33% errors compared to 19% errors when they recalled the sequences seven days later. Table 4.4.1.2 shows detailed stats for the recall time for DST and vIIS.

The recall time measured immediately after the training was not statistically significant using one-way ANOVA (p=0.12). However, statistically significant differences in recall time were noticed after seven days using one-way ANOVA (p=0.02). Turkey post hoc test reveals recall time for vIIS seven days later was statistically significant compared to DST.

Table 7.5. Recall time stats for Episodic Memory Task (in seconds)

Training Method	**Recall Time 1 Mean**	**Recall Time 2 Mean**	**Recall Time 1 Std Dev**	**Recall Time 2 Std Dev**
DST	32.15	51.22	10.24	10.84
vIIS	35.41	46.73	9.67	15.39

Table 7.6. Error Rate stats for Working Memory Task

Training Method	**Training Mean**	**Recall Mean**	**Training Std Dev**	**Recall Std Dev**
DST	5.71	4.31	3.91	2.92
vIIS	5.66	4.30	3.79	3.02

7.4.4 Error Rate

For the Working Memory task, the error rate was measured as the number of errors made by a participant throughout the training session and compared the error rate in the follow-up session after seven days. Figure 7.13 shows the box and whisker plot of error rate comparisons between DST and vIIS systems. On average, participants in the DST group had an average error rate of 5.71 during the training session and an average of 4.3 in the follow-up session. vIIS participants, on the other hand, had a mean error rate of 5.6 during the training session and an average of 4.3 during the follow-up study. Table 4.4.1.2 shows the statistics of error rate comparison between both groups.

7.4.5 SUS Survey

In the survey, the participants answered the System Usability questions on a 5-point Likert scale (1: Strongly Disagree, 5: Strongly Agree). Overall, the average SUS score for DST was 65 and for vIIS was 68. A SUS score of 68 and above is

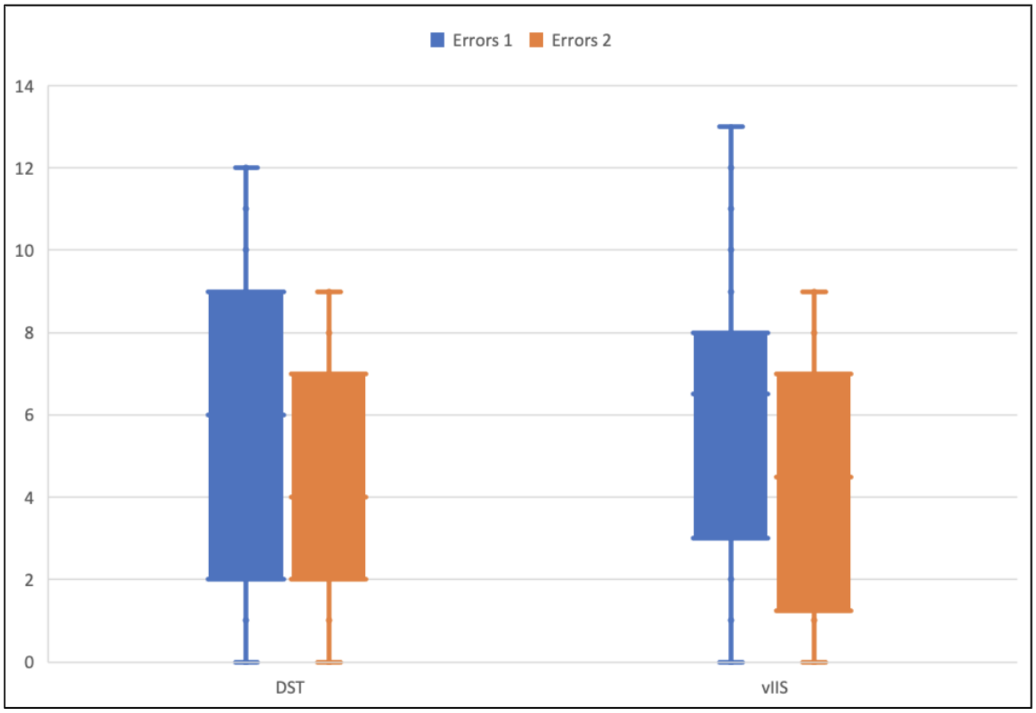

Figure 7.13. Error rate comparison between DST and vIIS.

considered above average. T-test was performed on the mean of SUS scores for both groups and found no statistical differences in the means of the SUS scores.

7.5 Discussion

A usability study evaluating the Desktop Storytelling system against the Vocational Interactive Immersive Storytelling system (vIIS) for providing training for two types of tasks, namely, Episodic Memory Task and Working memory Task, was conducted. For the episodic memory task, I observed a higher training time for vIIS users than DST users. I attribute this high training time to the users taking time to adjust to an AR application that may have increased the training time to a new interface. vIIS interface training pays off in long-term recall of learned content, as I have seen in the recall time and error rate. While the recall time increased for DST participants in the recall session, vIIS participants took less time to recall the content seven days later. In the Working Memory task, the number of errors made by the participants during the training and recall sessions for both DST and vIIS. Since the difference between both the systems is only in the interface and device used, it can be safely assumed that vIIS is as good as the traditional DST system considering all measured metrics in this study.

Both DST and vIIS systems have a limitation in how adaptive they are to a user's performance. However, the insignificance in the error rate between DST and vIIS shows that if the vIIS system is made adaptive, it can help reduce the error rate. Since vIIS performs about the same or better than DST, I recommend building upon the vIIS system to make it adaptive in the follow-up studies.

CHAPTER 8

vIIIS - VOCATIONAL INTELLIGENT INTERACTIVE IMMERSIVE STORYTELLING SYSTEM

This Chapter is partly based on the following publication

- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2018. vIIIS: A Vocational Intelligent Interactive Immersive Storytelling Framework to Support Task Performance. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA.*

All workers undertake some form of training when they join any vocation. Learning and training are highly advantageous to workers to stay up-to-date to newer technologies, retain job-relevant knowledge, learn new skills and abilities (Knowledge-Skill-Ability - KSAs) [114]. Every workplace requires that these KSAs are correctly applied during worker training to function effectively. Given the rise of Industry 4.0 and the explosion of other technology in recent years, the need for higher productivity, better service, better performance, cost reduction, high profits, and increased quality has increased dramatically. So in order to maintain high worker retention and high productivity, vocational training must provide the means for the workers to acquire and maintain the needed KSAs. In order to achieve this, training tasks need to be selected very carefully, meeting the requirements of the job.

Training and assessment of new workers are the most vital part of any vocational industry [3]. Innovations in science and technology have led to the creation of new industries and occupations, enhanced productivity and quality of work-life, and increased the potential for more people to participate in the workforce. Nevertheless, these come at the risk and disadvantage of an increased cost of training and lack of proper training in industries, such as manufacturing.

This Chapter presents the vIIIS Framework - A Vocational Intelligent Interactive Immersive Storytelling framework that uses storytelling and reinforcement learning in an adaptive interactive, immersive environment to train a repetitive object sorting task to a worker. The significant advantage of the vIIIS system is that it adapts based on the user input and provides constant feedback in an engaging and immersive augmented reality environment, thus offering better attention, engagement, and improved performance of the trained task. For assessment, I propose to collect data such as task completion time, accuracy, error rate, qualitative feedback such as perceived effectiveness and engagement. The impact of this work is that this framework can improve the workplace training process and make it adaptive for various demographics and minorities. Furthermore, with the help of intelligent learning algorithms, the framework can also be used for varying levels of complex training.

8.1 vIIIS Framework

vIIIS Framework is used to develop a system to support training and measure performance metrics from measuring accuracy and error rate. The primary component AR Environment encapsulates four other components of this framework. They are the human component User, the storyfication component, the AR rendering engine component, and the feedback Component. Figure 8.1 shows the high-level overview of the vIIIS framework.

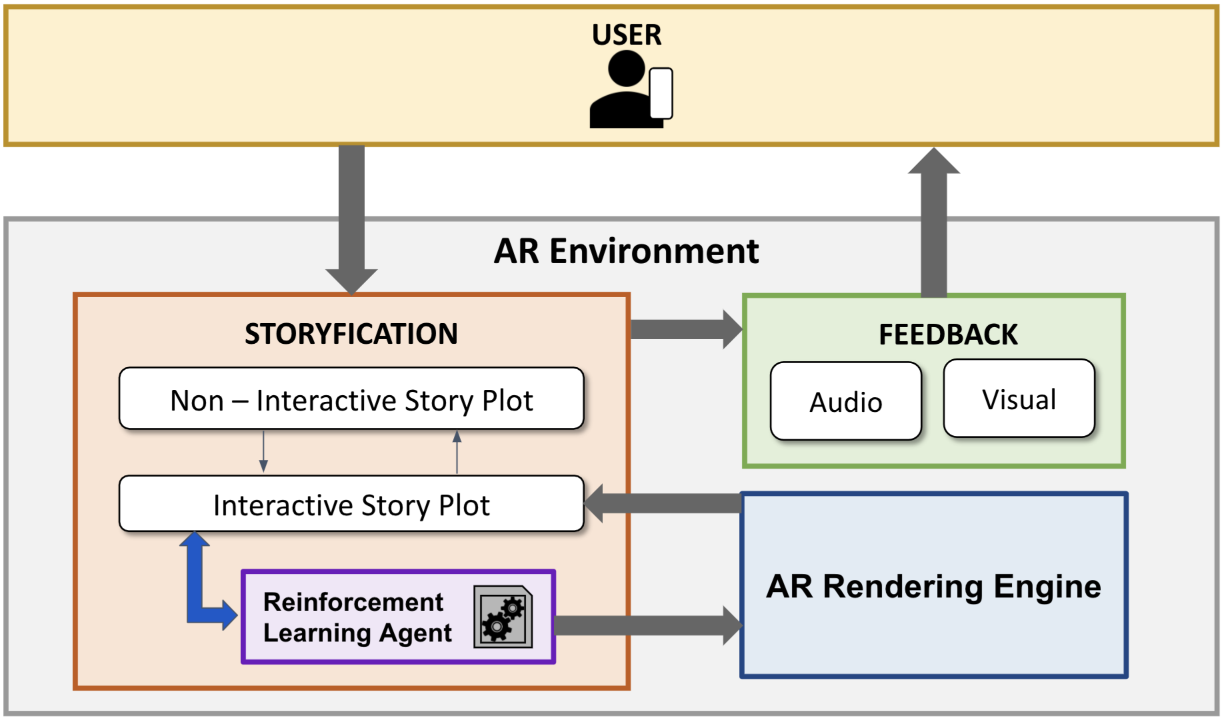

Figure 8.1. vIIIS Framework.

8.1.1 Immersive AR Environment

The AR Environment is the main component of the vIIIS framework which encapsulates all the other components. Augmented Reality is an immersive medium, and in our case, a handheld android device is used for displaying the augmented reality workplace environment. Because of this, the whole training and learning experience can be done in this immersive AR environment. The user sees and interacts with the virtual objects placed in the real world. The user is immersed in the AR environment during interaction and experiences the story like a real-life scenario. This aids better engagement.

8.1.2 User

The user is the human component in this framework. The user interacts with our vIIIS system by performing the task in the AR environment. The assumption is that the user will have little to no knowledge of the skill being taught using this framework. Another assumption is that the user neither has any disability nor visual impairment. Finally, as this system is based on a hand help mobile device, the assumption is that the user is comfortable in the AR environment as there is no need for extra equipment.

8.1.3 Storyfication

Interactive storytelling creates new media content for the presentation of a narrative that evolves a story dynamically. It can be modified and influenced by the user in real-time [115]. If combined with content gamification that uses game-based mechanics, aesthetics, game thinking to engage, motivate action, promote learning and solve problems in a non-game context, it can create a training environment that is rich in interactivity and adapts based on human performance. Gamification is applying game mechanics, elements, and game thinking when designing instructions to apply help move learners through instructions and alter the instructions' content. Storyfication refers to changing the story, adding gamified elements, and adapting the content independently from the visual medium used to present the narrative from text, audio, video up to computer graphics and virtual reality rendering systems [116]. Similarly, a part of storyfication was used by the vIIS framework [106], although it did not have the reinforcement learning agent.

In vIIIS, a repetitive task can be supported by adding storyfication to the training system. Storyfication adds story and content gamification elements to enhance the training and learning experience for the user.

8.1.3.1 Story

The story component is the heart of the system. The storyfication framework, as shown in Figure 6.5 describes how the story is created for the vIIIS system. The story follows the most common three-act structure, containing a Beginning, Middle, and End. This immersive interactive story comprises sub-components such as a non-interactive (NI) story plot and multiple interactive (I) story plots. The hook is a complicating incident that makes the user emotionally invested in the progression of the story. It also increases the interest of the user to participate in an interactive environment. This is a non-interactive story plot as no user input is required. The challenge section is where a user interacts with the system to solve a problem, in our case, to perform an object sorting task. The system supports the user with feedback. The user then gives a test in which he performs the task without support. The end of the story is non-interactive. It will define how the story ended based on the task performance of the user. The user can have the option to go back and do the tasks again at the Call to Action (CTA) stage. When viewing the narrative in an immersive environment, the user gets a first-hand experience into the actual training. The AR environment and the immersion both play a vital role in the training.

Non-Interactive Story Plot: The non-interactive story plot is a narrative that is like a training phase which is a view-only training mode (non-interactive). It resembles the traditional method of training where the introduction to the environment, instructions of the task are given. This story plot is non-interactive because I want the user to get familiar with the experience without any distraction.

Interactive Story Plot: The story can have any number of interactive story plots. These plots are interactive, where the user can perform a task to help the story narrative move forward. These interactive story plots in this experience are powered by a reinforcement learning agent that learns from the user input and adapts to keep the user engaged.

8.1.4 Reinforcement Learning Agent

The object sorting task has a total of six objects from which the user needs to select them in the right order. Each level has a difficulty D described as $D =$ [1,2,3,4,5] which is proportional to the number of objects to sort, N, where $N =$ [2,3,4,5,6]. The result of a given difficulty is described in terms of success, S, as $S =$ [0,1], with which the user receives a score defined as:

$$score = \begin{cases} \text{D}, & if success = 1 \\ \\ \text{-1}, & if success = 0 \end{cases}$$

The personalized Reinforcement Learning (RL) agent keeps track of the current difficulty level and task performance and learns an efficient training policy to control the task difficulty and storytelling feedback based on the user's actions. Thus, the RL agent aims to maximize task performance and assist the user in reaching higher levels (reward).

The RL agent is formulated as a Markov Decision Process (MDP). An MDP can be defined by a tuple (S, A, T, r, g) where S represents state space and A represents action spaces. $T(S'|s,a)$ and r(s,a) represents the dynamics and reward function and g e (0,1) represents the discount factor. The Conservative Q-Learning algorithm

Table 8.1. Encouraging and Challenging Feedback for vIIIS System

	Encouraging Feedback
success	"Good job!"
failure	"Try again with more focus"
	Challenging Feedback
success	"Excellent! Let's make it challenging."
failure	"Let's reduce the complexity. Sort few toys."

(CQL) [117] is utilized for offline learning to avoid overestimating values induced by the distributional shift between the dataset and the learned policy. Based on the CQL algorithm, the RL agent takes a conservative approach towards training the user to maximize the learning outcome. The RL agent also interacts with the storytelling rule engine to generate feedback after a user's attempt. Similar to [13], our system's feedback can be either encouraging or challenging feedback, as shown in Table 8.1.

During offline learning, a set of user models are collected which is then used by the Rl agent for personalized training. The agent can uses these models to learn and then update action policies for the user. Algorithm (Figure 8.2) shows how the agent performs live updates during a training session:

8.1.5 Feedback

The feedback component is integrated with the environment, which continuously analyzes the user's performance and reports the metrics on a graphical user interface in audio, visual, or haptic feedback. For example, the audio feedback could

```
Algorithm 1: Intelligent Storytelling Training Algorithm
Load Interactive story plot repository, ST_i;
Load Non-interactive story plot repository, ST_n;
Load Performance model, P;
Load training guidance model G;
Load Policy π; Initialize start state;
Initialize story plot;
while not done do
    Observe state s;
    Select action a based on π(s);
    Trigger action a based on G(s,a,g,P);
    Trigger ST_i and ST_n based on G(s,a,g,P);
    Observe user input, upcoming state s', reward r and story feedback f;
    Update P,G,π ;
    update s' = s;
    Update user policy π and its corresponding models
end
```

Figure 8.2. Intelligent Storytelling Training Algorithm.

be from a virtual avatar in the story; the visual feedback could be displayed on the user interface of the head-mounted display.

To supplement the training, the user could also be required to perform an offline evaluation of the learned task. Manual comparison of the offline evaluation can be compared against the performance of immersive evaluation, and the narrative can be adjusted accordingly.

8.1.6 AR Rendering Engine

The AR rendering engine is responsible for augmenting the virtual entities in the real world. The rendering engine initializes the default state with the virtual avatar and the environment. Once the training initiates, it interacts with the reinforcement learning agent to decide what scene and story plot to augment next. This main engine is key behind synchronizing the environment animation, audio, and visual feedback and rendering the proper training scene. Instead of having defined rules on what to display next, this engine fetches the result of given user interaction from the reinforcement learning agent and, using the response, maps the next scene to overlay. This engine also collects the user's interaction with the AR environment and sends the data to the reinforcement learning agent to process the next state.

8.2 System Design

Our vIIIS system is designed to make the repetitive object sorting task adaptive for the user using reinforcement learning and the framework described in the previous section. This is achieved in an immersive augmented reality (AR) environment, which depicts a workplace environment - an assembly line and a packaging station. The system also employs creative, non-interactive, and interactive fictional story elements and uses storyfication to make the system engaging and adaptive. This section gives an overview of the support training being provided in the object sorting task and then explains the two main components of our system: the story and the immersive augmented reality workplace environment, and provides the design decisions that went into the creation of our immersive story. The aim is to improve the working memory, also known as short-term memory but supporting the user during the object sorting task.

The system was implemented in Unity 3D with C# scripting and ARCore for AR development. I used Android phones for our training simulation and user studies.

8.2.1 Training Apparatus

We designed our system on a handheld mobile AR device to support users while performing object sorting. The Object Sorting Working Memory Test is designed to assess working memory (WM) as part of the NIH Toolbox Cognition Battery. Object Sorting is a sequencing task that requires users to sort and arrange the objects in a sequence based on the task's requirement; in our case, the users have to sort the objects in size order. The sequence stimuli are presented visually and via audio.

8.2.2 Story Design

The story design, story plot, and characters are the same as in Chapter 7.

8.2.3 Immersive AR Environment Design

Our augmented reality environment is based on a toy factory manufacturing plant's workplace. The environment has three active conveyor belts and one packaging workstations spread across the plant. There are two types of tasks done in this environment. The first one is the toy assembly task, and the second is the toy packaging station. The AR environment was viewed through an android mobile phone screen. As the viewing area is narrow, the AR objects in the environment are very few. Therefore, the AR environment looks clean and contains things that only contribute to the story. For vIIIS, the activity occurs at the packaging station, where the user needs to sort the toys into increasing size to fit them in their boxes for packaging. vIIIS system is based on the concept of storytelling and object sorting to help users

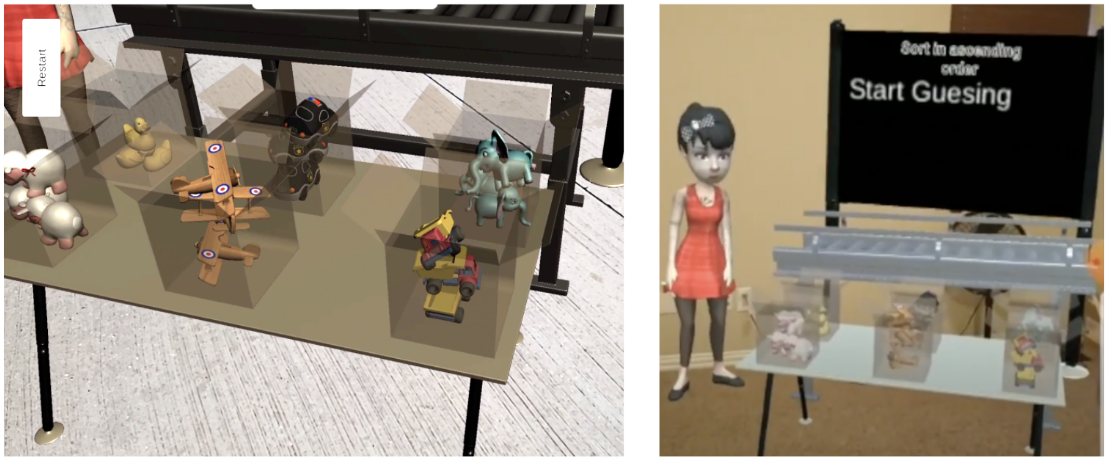

Figure 8.3. vIIIS System for Toy Packaging Task.

improve their working memory. First, the user was shown three objects (e.g., three types of vehicle toys such as car, truck, and airplane) which they need to sort in size order. Then the user is shown three more objects of another type (e.g., three types of animal toys such as a mouse, dog, and elephant) which they need to sort them in size order, first vehicles and then animals. Once this game is complete, there is an object sorting test in the end. Figure 8.3 shows our AR environment for the object sorting task.

8.2.3.1 Design Decisions

Many design decisions were made to create an intelligent, immersive, interactive fictional story. First, I started with storyboarding, scripting, dialogues recording, scene design, user interface design. Then, I made multiple iterations over the story's design to create a story that provides a sound support system while doing the packaging object sorting task while eliciting the user's right emotions to improve the user's working memory.

Design Decision #1 – Story format: We used the storyfication described in our vIIIS framework. It consists of the story that plays a massive role in how well the viewer stays connected and engaged with the story content and content gamification elements. The story becomes adaptive and increases the user's flow state. I designed our story based on our story format that chooses the standard form of narrative fiction, a *three-act structure*, beginning, middle, and end on a high level. These three sections contain details on how to write the story's script, so that correct emotions are elicited during the training. This story has two parts - non-interactive and interactive story elements. The most important part of the non-interactive story element is to provide a hook. The story's hook is critical to elicit the right emotions and keeps the user emotionally invested in the story. I ideated on multiple hooks and tested them using empathy maps in the Design Thinking Process. The story hook was that the toy factory could lose the order if do not finish the toy production on time.

Design Decision #2 – AR Environment User Interface Design: We decided to use handheld mobile devices for the augmented reality system. For any handheld AR device, ergonomics, ease of use, and intuitive display were considered. To reduce cognitive overload with too much information in the AR environment, I decided to display only the user's information for task experience. The interactive elements in the AR environments, such as toys, were fixed to a consistent location either in the virtual world. It is typically accessible for users to find and view content in screen space because it remains stationary while the underlying AR environment moves with the device. However, all the virtual objects and elements were fixed in space in our case. I also avoided much animation so that the user can entirely focus on the task without getting too distracted and to reduce lag which may cause motion sickness. The 3D assets used were designed to look like toys, and the avatar, Lily, was designed to be human-like to give a sense of reality. The height of the objects placed in the AR world is designed to be relative to the user's height.

Design Decision #3 – Dialogues and Sound An immersive story in an AR environment has less impact without a good sound design. This is because sound plays a huge role in how the user interacts, engages, and consumes the information from a story. Salselas et al. l [99] describes the role of sound in immersive storytelling and found that a good sound design modulates the attention of a viewer in a way that allows for an immersive user experience and allows the viewer to deduce that a narrative is being followed. In order to keep the users focused on the task, I added sounds in the form of dialogues and task feedback. For example, Lily, the factory worker who teaches and supports the user during the training session, is majorly spoken by the dialogues in the system.

Design Decision #4 – Scene Design As the system is designed for an android phone, the user controls the camera movement to allow the viewer to quickly focus on the main components of the story and have the freedom to look around the surrounding environment by moving the camera around in the space. For example, when the users initiate the training, they can see a toy factory workplace around them. Three sides contain assembly lines for assembling toys, and the fourth side contains the packaging staging. All the virtual objects are fixed in space to move around and get closer or far away from the objects based on their convenience.

Design Decision #5 – Task Design The task selection was based on the use cases of the project. I have assigned tasks for each of the use cases based on their requirements and conditions. For example, training systems can train, educate and inform several information in assembly and factory workplace. The two use cases are teaching a new skill and adaptive tasks to support users. Our vIIIS focuses on improving the second use case's experience and performance.

The adaptive task to support users: Continuous quality support is the key to high retention of skilled workers in the workforce. As the technologies are evolving rapidly, the need to train, re-train and support workers is higher than ever. Therefore there is a need for training systems at the workplace that provides continuous support for workers during a task. This could be helpful if the task is cognitively demanding.

Task: The task is to support the user while sorting animal and vehicle toys in size order in a toy factory. Object Sorting task adapted from NIH is used. The user was asked to sort six objects in size order in increasing order.

Design Decision #5 – Avatar Only one character, Lily, the factory worker and protagonist's friend, is shown in the AR environment. This avatar explains the tasks to the user and also gives feedback. The avatar appearance plays a significant role in how the user perceives the environment. [The Effect of Avatar Appearance on Social Presence in an Augmented Reality Remote Collaboration] found that a realistic whole body avatar was perceived better than cartoon avatars for remote collaboration. This is true in adaptive training in an immersive AR environment that the task is done more like a remote collaboration than a stand-alone task training.

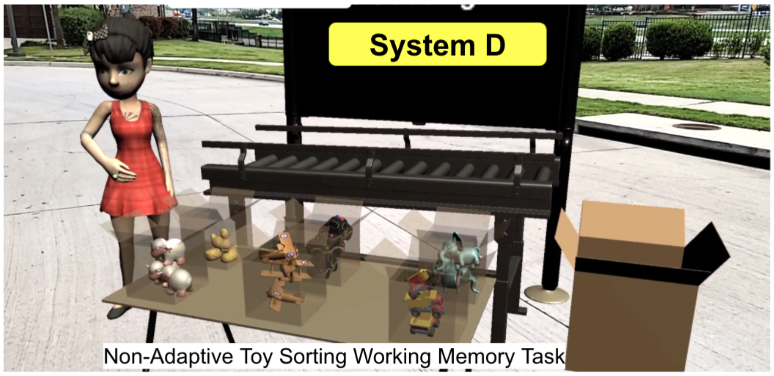

Figure 8.4. vIIS (System D) vs vIIIS System(System E).

8.3 Study Design

In order to examine whether the immersive platform (vIIS) is better than intelligent, adaptive training systems (vIIIS), two training systems for working memory were designed, keeping the tasks and the storyline the same (Figure 8.4).

vIIS System (D): (Chapter 7) The Augmented Reality mobile-browser-based can be played on the user's mobile phone. The user downloaded the app and began the user study. First, the user was shown an immersive story with sound and 3D objects in their space where they walked through a scenario. The scenario was that the user needed to sort toys for packaging. Next, the user practiced the toy sorting task. After the practice session, the user gave a test. The test was the same task.

Adaptive vIIIS System (E): The Augmented Reality mobile-browser based can be played on the user's mobile phone. The user downloaded the app and began the user study. First, the user was shown an immersive story with sound and 3D objects in their space where they walked through a scenario. The scenario is that the user is a factory trainee, and they need to start training. Next, the user practiced the picture sequence task and then the object sorting task. After the practice session, the user gave a test. The test was the same task, but support would be given from the system. The only difference between System D and E is that system E is adaptive and helps the user to perform better by learning from user input and according to setting task level.

8.3.1 Study Procedure

To measure the task performance of these systems D and E, I developed a between-subjects experiment in which participants were allocated, in round-robin, to one of the two training methods for working memory. Our user study was divided into two phases with a gap of seven days between both phases (Figure 8.5).

Day 1 Training session: Participants were presented with an Informed consent form. After giving consent, participants were assigned to one of the working memory training methods to interact with the assigned system and trained. Once the toy sorting task training with all two types of toys (6 toys) was complete, they were given a test of 6 toys that were a part of the story. After using their respective systems, in the end, the users were asked to fill out a questionnaire. Their answers, along with the SUS scale responses, were then collected.

Day 7 Recall Session: (seven days after a training session). Participants were sent a reminder to use the system after seven days. They were asked to use the system and only give the test. They were shown the story and were asked to sort 6 toys for 10 minutes.

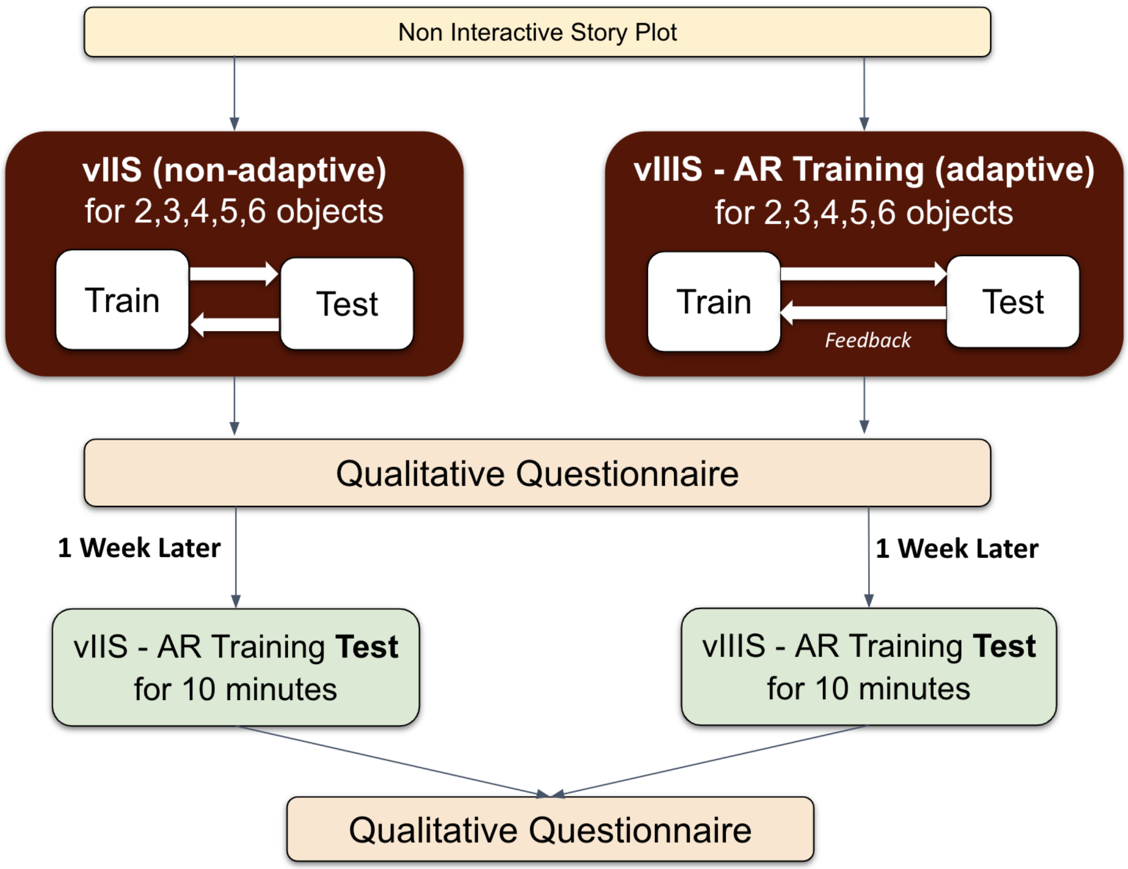

Figure 8.5. vIIS vs vIIIS Study Procedure.

8.3.2 Participants

The study was conducted online and was approved by the University's Institutional Review Board (IRB). I hosted the study and recruited participants through the Amazon Mechanical Turk website [113]. 80 participants were selected for this study, 40 participants were recruited for each group. The participants from the age group 18 to 40 were required with good sight and no disability.

8.3.3 Data Collection

For each of the above study groups, the following data were collected:

1. Task performance was captured by measuring the time taken and the number of mistakes (task accuracy). Time is taken to complete each task
2. Time taken to complete the task
3. User's score for each level in the task
4. How many tasks the user completed successfully at each level
5. Time spent on each level of the task
6. Survey data
7. Satisfaction is an index used to qualify the user's feeling of adequacy with a given situation. The overall satisfaction was captured after each condition for each participant by self-assessment on a 5-point scale (range 0 to 4)

8.3.4 Duration

This study was remote and could be completed any time based on the participant's time availability. It would take about two sessions, the first being 45-60 minutes and the second 15 minutes long. The second session was conducted one week after the participant had participated in the first session.

8.4 Results

8.4.1 Demographics

Our usability study was hosted as Human Intelligence Task on Amazon Mechanical Turk. I enrolled 80 participants in our usability study. 40 random participants were assigned to the vIIS System and the remaining 40 participants were assigned to the vIIIS System. Among the participants who reported their age, the age ranges varied from 18 to 40, with a mean age of 34. In addition, 59% of the participants identified their gender as male, 37% identified as female, and the rest preferred not to answer.

8.4.2 Error Rate

The error rate is measured as the number of errors made by the participant throughout the training session and during the recall session. The error is defined as an incorrect object sorting task for a given level. Figure 8.6 shows the whiskers and box plot graph for the error rate comparison between the vIIS and vIIIS system. I found that users of the vIIS system made an average of 4.44 errors during the training session compared to 2.62 errors for the vIIIS system. During the recall session seven days later, the average error rate for vIIS rose to an average of 4.73 compared to a slight increase to an average of 2.73 in the vIIIS system.

8.4.3 Experience Survey

A survey of user experience was conducted after the training and recall session in vIIIS to understand the user's experience using the vIIIS system. Figure 8.7 shows the survey data I received after the training session. As is evident from the survey responses, I found that most participants would want to use the vIIIS system frequently due to its ease of use.

8.5 Discussion

In this Chapter, I proposed a vIIIS framework. An Intelligent, Interactive Immersive Storytelling system uses storytelling in an Interactive augmented reality environment to train and support the worker while doing a task. The four components of the vIIIS framework were explained that included human component user,

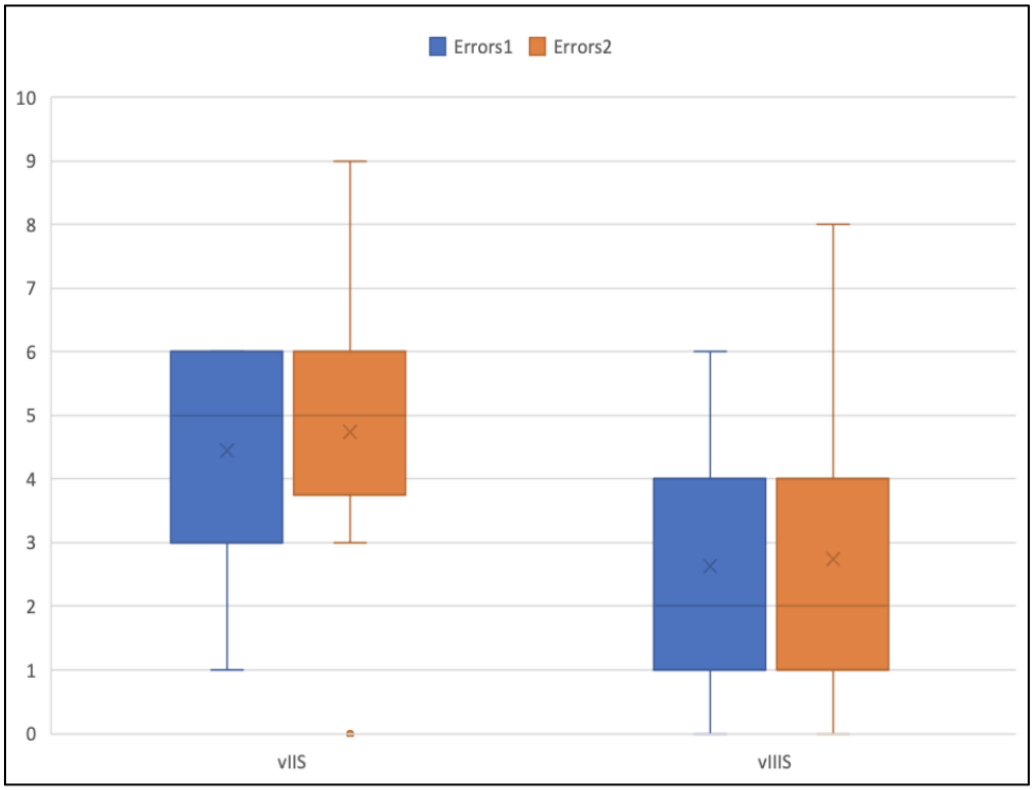

Figure 8.6. Error rate comparison between vIIS and vIIIS.

the storyfication component, the AR rendering engine component, and the feedback Component. The immersive AR system design, Story design, and design decisions were also described and played a significant role in a training environment. I collected data such as task completion time, accuracy, error rate, and qualitative feedback such as perceived effectiveness and engagement for assessment.

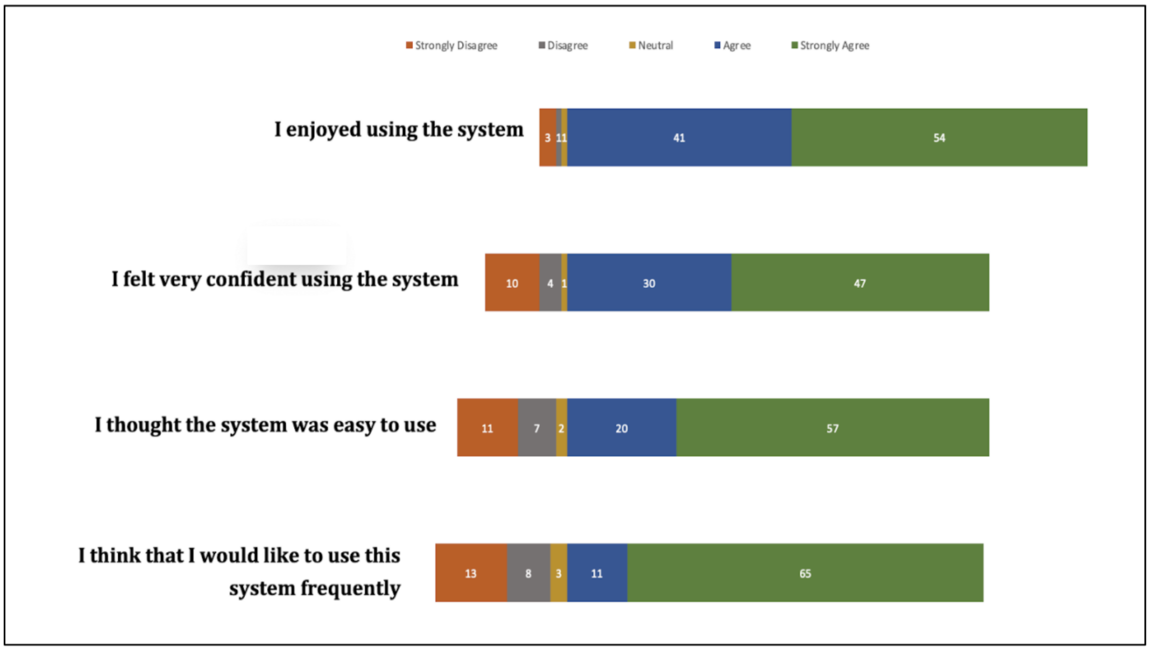

Figure 8.7. User Experience Survey for vIIIS System.

CHAPTER 9

VISTAS - VOCATIONAL IMMERSIVE STORYTELLING TRAINING AND SUPPORT FRAMEWORK

This chapter is partly based on the following publication

- *Sanika Doolani, Callen Wessels, and Fillia Makedon. 2021. Designing a Vocational Immersive Storytelling Training and Support System to Evaluate Impact on Working and Episodic Memory. In PETRA '21: The PErvasive Technologies Related to Assistive Environments (PETRA), June 29– July 02, 2021, Corfu, Greece.ACM, New York, NY, USA*

The VISTAS framework is designed to combine vIIS and vIIIS framework powers to improve episodic memory and working memory, respectively. In this chapter, the VISTAS framework is used to develop a system to train the user in an assembly task and support the user and measure performance metrics from measuring accuracy and error rate. The primary component AR Environment encapsulates four other components of this framework. They are the human component User, the storyfication component, the AR rendering engine component, and the feedback Component. Figure 9.1 shows the high-level overview of the VISTAS framework. All the components of the VISTAS framework are similar to the vIIIS Framework (Chapter 8) except the interactive story plot of the Storyfication component. This chapter inves-

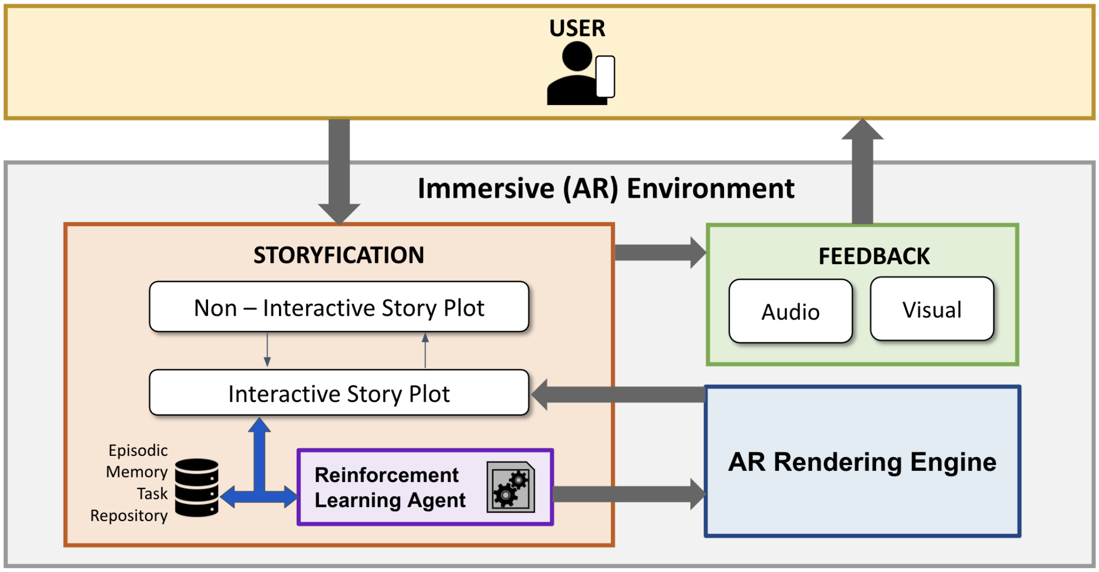

Figure 9.1. VISTAS Framework.

tigates whether the VISTAS system is better than vIIS - interactive, non-adaptive, immersive system for vocational training.

Interactive Story Plot: The story can have one or many interactive story plots. These plots are interactive, where the user can perform a task to help the story narrative move forward. These interactive story plots in this experience are powered by a reinforcement learning agent that learns from the user input and adapts to keep the user engaged. The tasks are selected from the episodic memory task repository or the reinforcement learning agent for working memory tasks. Storyfication enriches the user's experience. These interactive story plots not only provide more intense training but also assess the performance of the user. In contrast to the non-interactive story plot, where the user only views the training narrative, the user also interacts within the immersive environment to get hands-on training on the learned task.

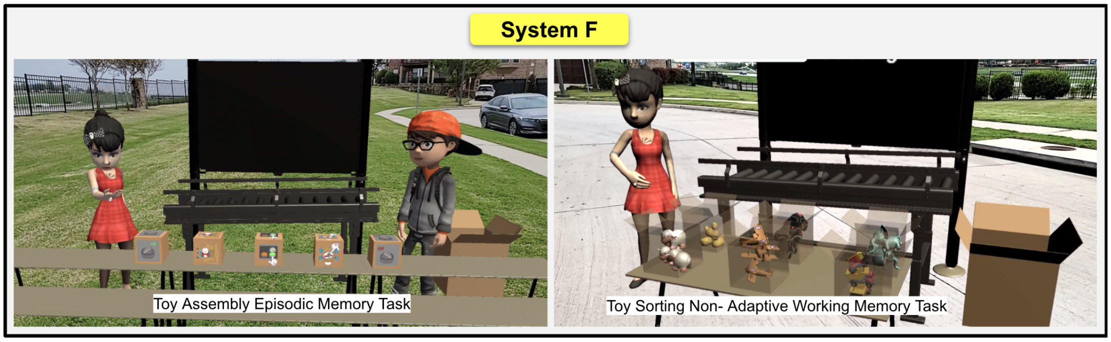

Figure 9.2. vIIS System (System F).

9.1 Study Design

In order to examine whether the vIIS platform consisting of episodic memory task and non-adaptive working memory task is better than VISTAS training system consisting of episodic memory task and adaptive working memory task, we decided to conduct our user study by using these two systems - vIIS and VISTAS.

vIIS System (System F): This system was a combination of previous systems C and D (Chapter 7). The Augmented Reality mobile-browser-based can be played on the user's personal mobile phone (Figure 9.2). The user downloaded the app and began the user study. First, the user was shown an immersive story with sound and 3D objects in their space where they walked through a scenario. The scenario was that the user is a factory trainee, and they need to start training. Next, the user practiced the toy assembly episodic memory task and then the non-adaptive toy sorting working memory task. After the practice session, the user gave a test. The test was the same two tasks, but no feedback or support would be given from the system. For the test, the user performed the toy assembly episodic memory task for

Figure 9.3. VISTAS System (System G).

only sequence 3 and performed the non-adaptive toy sorting working memory task for 10 minutes.

VISTAS System (System G): This system combines previous systems C and E (Chapter 7 and 8). The Augmented Reality mobile-browser-based can be played on the user's personal mobile phone (Figure 9.3). The user downloaded the app and began the user study. First, the user was shown an immersive story with sound and 3D objects in their space where they walked through a scenario. The scenario was that the user is a factory trainee, and they need to start training. The user practiced the toy assembly episodic memory task and then the non-adaptive toy sorting working memory task. After the practice session, the user gave a test. The test was the same two tasks, but no feedback or support would be given from the system. For the test, the user performed the toy assembly episodic memory task for only sequence 3 and performed the non-adaptive toy sorting working memory task for 10 minutes. The difference between System F and G was that system G was adaptive

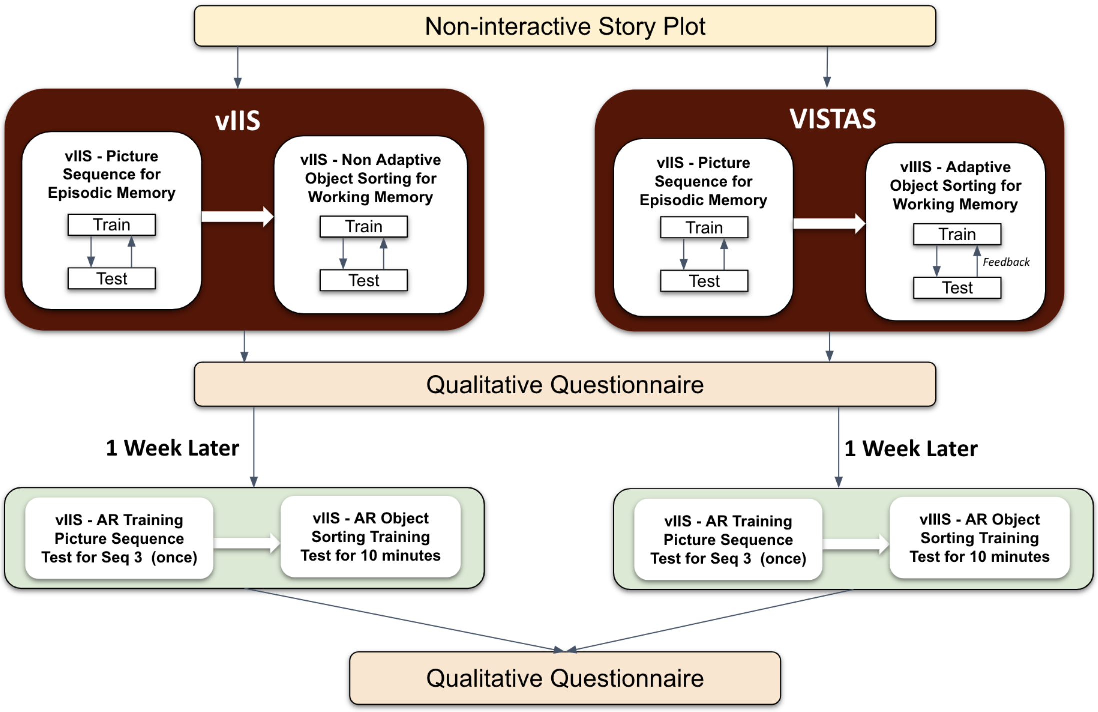

Figure 9.4. vIIS vs VISTAS User Study Procedure.

and helped the user to perform working memory tasks better by learning from user input and according to setting task level.

9.1.1 Study Procedure

In order to empirically evaluate the above research questions, we developed a between-subjects experiment in which participants were allocated, in round-robin, to one of the two training methods for working memory and episodic memory combined user study (Figure 9.4)

vIIS System (System F): In this method, the participants were given an AR android app. The immersive story was shown on the AR mobile app. The users were asked to conduct the user study in a quiet location with a spacious floor to view the AR objects through the app.

VISTAS System (System G): The participants were also given an AR android app. The users were asked to conduct the user study in a quiet location with a spacious floor to view the AR objects and perform the tasks.

1. The participants were asked to read through this Informed Consent and email the Principal investigator if they had any questions; then make their choice about whether to participate.
2. They were randomly selected for one of the four systems.
3. Training Session: They were asked to use the system and practice the tasks. In the practice session, the system taught them how to complete the task and feedback for their inputs.
4. Test Session: After completing the practice sessions, the participants were asked to complete the task again.
5. They were asked to fill out a questionnaire. The questionnaire contained questions asking about age, gender, how will the user rate their experience playing the game, how will they rate their memory completing their, did they enjoy, was the task effective, was there any discomfort, and an open-ended comment they might have.
6. They were asked to retake a test session one week later.
7. They were asked to fill out a questionnaire again; this was the same as the previous questionnaire.

To measure the learning and recall of these methods, our user study was divided into two phases with a gap of seven days between both phases.

Day 1 Training session: Participants were presented with an Informed consent form. After giving consent, the participants interacted with the assigned system and were trained. Once the training for the task with all three sequences was complete, they were given a test of sequence 3 that was a part of the story. Then the participants were assigned to the working memory task and trained. Once the toy sorting task training with all two types of toys (6 toys) was complete, they were given a test of 6 toys that were a part of the story. After using their respective systems, in the end, the users were asked to fill out a questionnaire. Their answers, along with the SUS scale responses, were then collected.

Day 7 Test Session (seven days after a training session): Participants were sent a reminder to use the system after seven days. They were asked to use the system and only give the test of sequence 3. First, they were shown the story and asked to perform sequence three of the toy assembly task. Then they were shown the story and were asked to sort 6 toys for 10 minutes.

9.1.2 Participants

The study was conducted online and was approved by the University of Texas at Arlington's Institutional Review Board (IRB). We hosted the study and recruited participants through the Amazon Mechanical Turk website [113]. 70 participants were selected for this study, 35 participants were recruited for each group. The participants from the age group 18 to 40 were required with good sight and no disability.

9.1.3 Data Collection

For each of the above study groups, the following data were collected:

1. Task performance was captured by measuring the time taken and the number of mistakes (task accuracy). Time is taken to complete each task
2. Time taken to complete the task

3. User's score for each level in the task
4. How many tasks the user completed successfully at each level
5. Time spent on each level of the task
6. Survey data
7. Satisfaction is an index used to qualify the user's feeling of adequacy with a given situation. The overall satisfaction was captured after each condition for each participant by self-assessment on a 5-point scale (range 0 to 4)

9.1.4 Duration

This study was conducted remotely and could be completed at any time based on the participant's time availability. It would take about two sessions, the first being 60-75 minutes and the second 30 minutes long. The second session was conducted one week after the participant had participated in the first session.

9.2 Results

9.2.1 Error Rate

Figure 9.5 shows the error rate comparison between vIIS and VISTAS. The average error rate for vIIS and VISTAS was 6 and 4, respectively, with both having about the same standard deviation. One-way ANOVA test revealed statistically significant differences (p=0.0033) between both error rates and turkey post-ad-hoc test showed VISTAS error rate was statistically significant than vIIS. Table 4.4.1.2 shows a summary of the error rate statistics between both systems.

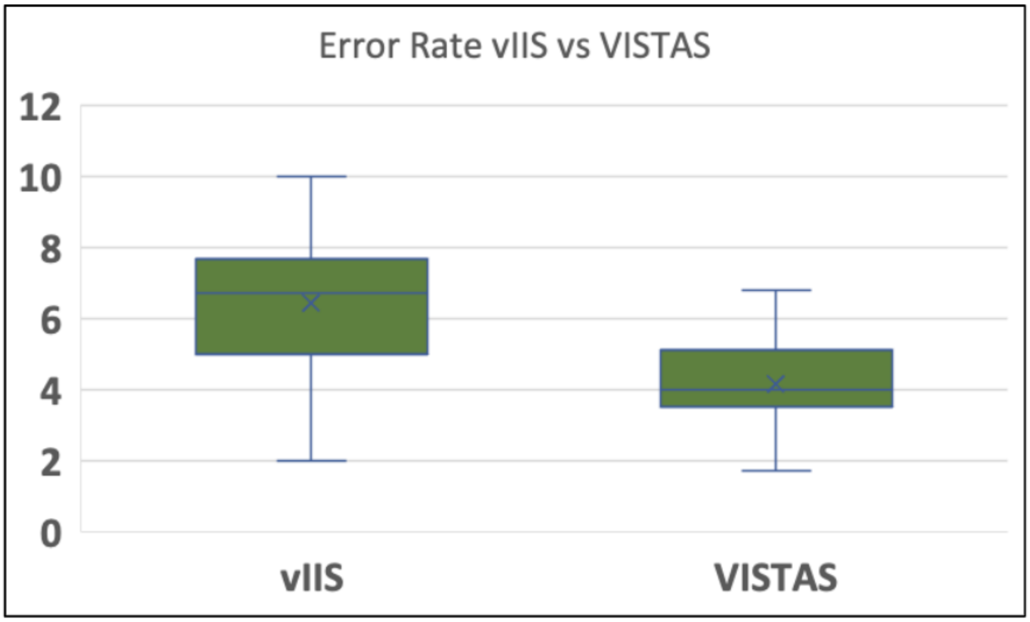

Figure 9.5. Error Rate comparison between vIIS and VISTAS.

Table 9.1. Error rate comparison between vIIS and VISTAS

Training Method	**Mean**	**Median**	**Std Dev**
vIIS	6	7	1.97
VISTAS	4	4	1.24

9.2.2 Training Time

Figure **??** shows the training time comparison between the vIIS and VISTAS system. vIIS had an average training time of 529 seconds, whereas VISTAS had an average training time of 579 seconds. Table 4.4.1.2 shows the detailed statistics of the training time we measured. In addition, an independent t-test revealed statistical significance in the means of both the systems (p=0.00044).

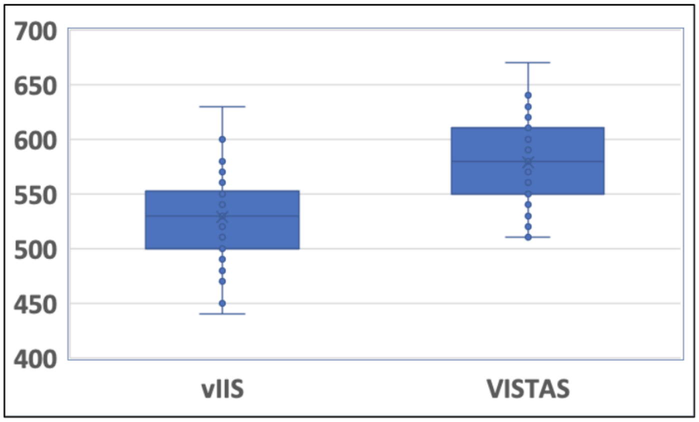

Figure 9.6. VISTAS Training Time.

Table 9.2. Training time comparison between vIIS and VISTAS

Training Method	Mean	Median	Std Dev
vIIS	529	530	39.75
VISTAS	579	580	41.32

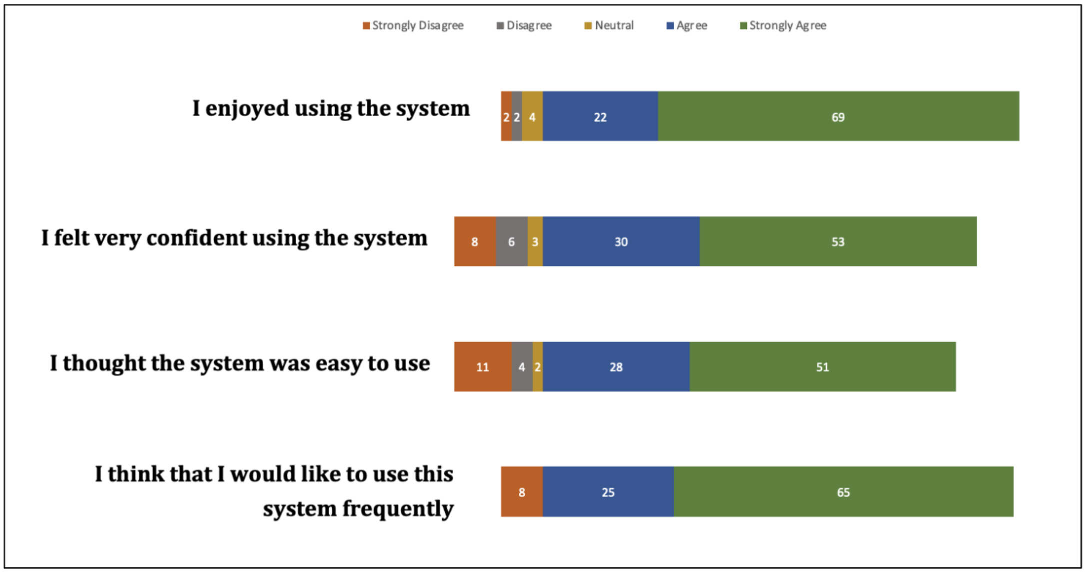

Figure 9.7. VISTAS.

CHAPTER 10

GUIDELINES FOR DESIGNING VISTAS SYSTEM

Based on the experience I gained from designing the (VISTAS) intelligent, interactive, immersive storytelling system in different scenarios for working and episodic memory tasks with different user groups, I propose designing and implementing VISTAS systems in the workplace. Although these guidelines and recommendations were inspired by using VISTAS systems at workplace scenarios, I suggest that they can be transferred to other scenarios involving educational or vocational training systems, e.g., for a smart home scenario.

10.1 Feedback Design

Interactivity is a two-way street; the user input should be matched with efficient and informative feedback that promotes learning. When designing feedback for VISTAS systems, the designer should consider two essential aspects: First, the feedback should contain all necessary information relevant to the task. Second, the feedback should be as simple as possible embedded in the story to elicit an emotional response from the user. As the two aspects are contrary, the minimum trade-off that still fulfills both requirements needs to be found. In the studies, I showed that giving text feedback should be avoided as some workers cannot read. Instead, simple feedback from the avatars was more welcomed by the users. Further, I found that too many objects in the immersive environments should also be avoided as they transfer a lot more information than what is necessary to complete the task. As the best trade-off between the two requirements, I found that using simple sentences for feedback with a small sound effect for showing assembly steps is a good way of fulfilling both requirements.

10.2 Display in immersive environment

Training in immersive environments was tested in virtual and augmented reality systems. I found that they have many possibilities to display feedback and instructions to users. For example, through the experience with VISTAS systems, I learned that crucial information like following the main character, looking at the assembly task being taught, and interactivity instructions should be displayed directly at the position where the action is required. When displaying then on a screen located in close proximity to where the actions are required, users can transfer the learned instruction experienced in the immersive to the real world. This reduces cognitive effort, makes it time-efficient, and reduces error. Furthermore, keep all the AR objects near the user according to their height makes it affordable and easy for user interaction.

10.3 Story Design

The story should contain all the elements of the storyfication framework for more significant impact. The storyfication framework is designed to balance interactive and non-interactive story plots that help create an informative yet emotionally fulfilling story. Using a VISTAS system should not result in additional learning outside the system and should not limit the user in performing their tasks. Therefore, I emphasize that the story should contain all story elements. If the user would have to remember information outside of the story, the user's mind would always be occupied by unrelated information. Based on the recognized task, story and feedback should be displayed.

10.4 Enable user to control their performance

When analyzing the design space of VISTAS systems, the dimension of where to put the immersive technology is essential. VISTAS training systems can be in a head-mounted immersive environment or hand-held mobile and carried by the user. Also, hybrid approaches exist, which I scoped out of the research due to resource restrictions. Nevertheless, they can be achieved in mixed reality environments. Through many studies I conducted, I recommend to instead equip the environment with the technology of the VISTAS system than equipping users with technology. Only keep the necessary technology for the training systems. I learned that users do not want to wear any other technology, such as any sensors, when performing a work task.

10.5 Interaction Design

Strive for intuitive, natural interaction when designing for immersive environments. I distinguish two scenarios: interacting with the system regularly to practice tasks and test and view the non-interactive story plots. The interaction with the system should happen based on natural instinctive interaction and detecting activity. Most of the interaction depends on the task design. The task should be selected based on the goal of training. If the task is repetitive, the intelligent module of the VISTAS framework should be used. Further, as designers of VISTAS systems, keep in mind the experience level of the users who will be using the system. The expert user should have the task, story, and interactions based on their knowledge.

10.6 Add motivating task information

From the questionnaires, I learned that participants would wonder how many task items were left in the current task and how fast they were during the studies. Some participants suggested they have this information always present while performing their work tasks. Although I had scores displayed, they wanted a clear breakdown of task score, time left, and overall success score. This could be as simple as displaying a progress bar that fills up when completing more work steps, or more complex with a leader-board that shows which worker made the fewest errors or which worker produced the most parts. Displaying quantified-self information can be closely linked to adding gamification elements to enhance work processes, which was suggested by [118]. Designing VISTAS systems in a way that users can always view their quantified-self information will lead to higher motivation and engagement during monotonous tasks in between stories when using systems.

CHAPTER 11

CONCLUDING REMARKS AND FUTURE DIRECTIONS

This dissertation explores how Augmented Reality Storytelling Training system can be used to train and support inexperienced workers and experienced workers, and improve their episodic and working memory during assembly or sorting tasks. To investigate this, a user-centered design process with multiple iterations and a bottom-up approach was followed. First, the workers' requirements were collected by doing field research. Then frameworks were built and systems were implemented based on those frameworks to understand the workers' performance improvement and learning in more depth. In this chapter, the research contributions addressed in this dissertation are summarized. Further, the following steps for future work are pointed out.

11.1 Summary of Research Contributions

The main contribution of this dissertation is six-fold.

vIS: First, I investigated and applied a user-centered design process with multiple iterations for identifying requirements for the immersive storytelling system that can be applied to both manual assembly workplaces and to find whether vIS training is better than other traditional methods of training such as video training and text-based manual training. By applying the user-centered design process, the use-cases for immersive storytelling systems at the workplace were identified. Two significant scenarios were found: training workers for a new task and providing continuous quality support for workers to improve cognitive abilities.

Storyfication: Second, a Storyfication framework was designed to create stories fit for training. The storytelling framework combines a traditional storytelling graph consisting of the beginning, middle, and end components of a story and gamification elements that make the interactive story plots of the immersive story engaging and make the user emotionally invested in the story.

vIIS: Third, I presented the vIIS framework, implemented a system using the vIIS system, and proved that it performs better compared to 2D based desktop system for episodic memory-based tasks. Episodic and working memory is essential for short and long-term recall of the information learned during task training. vIIS proved to be a better system than a 2D desktop-based training system for episodic memory tasks, but a potential to improve the working memory tasks was found.

vIIIS: Fourth, I presented the vIIIS framework and implemented an intelligent, adaptive training system to better support the user during tasks designed. To improve the working memory tasks that are primarily repetitive, reinforcement learning makes the immersive story adaptive based on the user's input during the task training proved the improve attention, performance, and engagement of users.

VISTAS: To improve the episodic and working memory of the user during training to impact the long term recall and attention, for the assembly workplace, the fifth contribution is the unified VISTAS system that is a combination of vIIS system for the episodic memory tasks and vIIIS system for the working memory tasks.

Guidelines for designing VISTAS system: Lastly, in the sixth contribution, I formulated and presented guidelines for designing VISTAS to create task training and support systems for workplaces. These guidelines are based on the research and experience with immersive systems for the workplace. As a result of designing, implementing, and evaluating immersive systems for approximately three and half years, I presented six guidelines for designing intelligent, interactive, immersive storytelling systems for vocational training. They should help designers and researchers understand the design decisions that worked well with the users and the concepts that did not work well. I based these guidelines on our experience that I gathered from applying our immersive storytelling system in many different manufacturing training scenarios, e.g., using a mechanical micrometer, assembling a toy in a toy factory, and sorting the toys based on shapes and size for toy packaging.

11.2 Future Work

This dissertation investigates how interactive, immersive stories can be used for training and cognitively supporting workers during vocational training in assembly workplaces. As I conducted research and implemented the proposed frameworks to conduct user studies, I identified other exciting areas of research beyond the scope of this dissertation. In this section, I present these areas for future research.

11.2.1 Exploring the transfer learning

As I found that intelligent, interactive, immersive storytelling training systems can be used to train inexperienced workers for learning new assembly tasks and also get support during the repetitive task, it would be interesting to investigate how well do they perform these tasks in real-world scenarios after getting training in immersive environments. A research project could compare the performance of VISTAS training instructions to the performance of a real assembly task in an actual workplace. This could be done by conducting a lab study, where participants have to learn how to assemble a product using the VISTAS training system and then perform a test in the immersive training system and the real world. As a further step, the performance of these tasks could be explored in real manufacturing scenarios.

11.2.2 Extending VISTAS to Other Application Areas

There is considerable potential for supporting workers at workplaces other than manufacturing. In future work, this concept could be extended to support persons for educational, domestic work-based training. The only requirement of using VISTAS is that the user should interact with the immersive story to get trained. One example could be using VISTAS to train for preparing meals in the kitchen or to use VISTAS for helping adults and seniors improve their cognitive performance for routine tasks in the morning. Additionally, this concept could also be evaluated as smart place training. Considering a smart home scenario, e.g., a family member could be using VISTAS to train the house-help to do a specific set of tasks when no one is there at home.

11.3 Concluding Remarks

This dissertation investigates how interactive, immersive stories can be used for training and cognitively supporting workers during vocational training in assembly workplaces. Further, I designed the VISTAS framework to make the training system adaptive by using the reinforcement learning method, thereby increasing the user's attention, performance and improving the user's working memory. The concept of Storyfication to create interactive stories design for training was introduced. The VISTAS framework significantly impacts the design of training systems where assembly tasks are performed. Having an immersive storytelling system through virtual, augmented, or mixed reality mediums in every assembly workplace could change how workers are trained on the job and even how training systems are being produced. Storyfication increases the long-term recall of the task instructions learned during the training sessions. With VISTAS, immersive technologies being commercially available, and the promising results that this dissertation provides, the framework will genuinely become ubiquitous in some years.

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BIOGRAPHICAL STATEMENT

Sanika Doolani (formerly Sanika Gupta) was born in Mumbai, India. In 2014, she received her Bachelors of Computer Engineering degree from the University of Mumbai. She started pursuing her Masters's in Computer Science at The University of Texas at Arlington (UTA) in 2014 and joined the Heracleia Lab in 2015. In her Master's Thesis, she conducted user-centered research for training a second language using virtual reality. Her project was highly successful and earned her a lot of awards.

She started her doctoral program in 2016. As a researcher of Heracleia lab at UTA, she worked as a graduate teaching assistant, participated in NSF-funded projects research with her colleagues, published several journals and research papers in international conferences under the supervision of Prof. Fillia Makedon. She successfully defended her Ph.D. in April 2021.

Sanika has volunteered and participated in Student Computing Research Festival (SCRF) hosted by the UTA's Computer Science and Engineering (CSE) department (2020 - 2021). She served as a panelist at UTA's OurCS@DFW and shared "The Graduate School Experience". She represented CSE department at the Grace Hopper Celebration of Women in Technology conference (2018 - Present). She became a brand ambassador for Salesforce at UTA. Over the years, Sanika participated in all biannual meetings of the iPerform NSF center, giving talks, presenting posters, and interacting with companies who came. She also was an organizing committee member at the International Conference Petra, where she peer-reviewed papers and has received annual Doctoral Consortium NSF travel awards for her publications for several years.

During her Ph.D., she interned at The Walt Disney Company (2019) and Salesforce (2020) as a User Experience (UX) designer. The work Sanika did at Disney is closely related to her research at the Heracleia Lab. Disney's work revolved around storytelling. They wanted to combine all the emerging technologies such as VR, AR, Artificial Intelligence into their movies and theme park experiences. Sanika directly applied her Ph.D. research in the work she did at Disney. At Salesforce, she worked on an internal product powered by Artificial Intelligence (AI). She conducted qualitative and quantitative user research, analyzed the user data, and suggested re-design of their user interface. Her role included understanding, researching, and suggesting improvement of an AI application. Her research interests revolve around Human-Computer Interaction, focusing on UX design, and designing for emerging technologies and new user interfaces. Sanika will be joining Salesforce as a Product (UX) Designer.

Over the years at The University of Texas at Arlington, Sanika has won many awards/rewards for her research and showcasing her research projects at entrepreneurial competitions.

- **Outstanding Doctoral Candidate Award** - Awarded by the Academic Excellence Ceremony at the University of Texas at Arlington, $1500 (2021)
- **Research Lightning Talk – Best Project Presentation Runner Up Won** - Awarded for presenting my Ph.D. research at Student Computing Research Festival (2021)
- **Outstanding Graduate Teaching Assistant Award** - Awarded by the Academic Excellence Ceremony at the University of Texas at Arlington, $1000 (2020)
- **Design X Social Challenge 2020 FINALIST** - Awarded for ideating, designing, and presenting our solution At Your Service, which is a mobile app so-

lution for 'Life during Pandemic'. Our team was in the Top 30 amongst 5000+ participants. (2020)

- **Research Lightning Talk - Honorable Mention** - Awarded for presenting my Ph.D. research at Student Computing Research Festival, UTA (2020)
- **Outstanding Doctoral Candidate Award** - Awarded by the Academic Excellence Ceremony at the University of Texas at Arlington, $1000 (2019)
- **UTA Maverick Business Pitch Competition – 6th Place** - Awarded for pitching a business idea on Augmented Reality. Received $8000 as development funds for presenting my research project as a business idea (2018)
- **Grace Hopper Scholar** - Awarded by Grace Hopper Celebration Women in Computing. (2018)
- **PETRA Conference Doctoral Consortium Award** - Awarded by PETRA Academic International Conference, Greece (2018)
- **Startup MavsChallenge, First Runner Up** - Awarded $2000 by the University of Texas at Arlington, College of Business for presenting my master's thesis project as a business idea (2017)
- **Verizon Outstanding Master's Thesis Award** - Awarded by Verizon and College of Science and Engineering for my Master's Thesis (2016)
- **Fan Favorite Award 3rd Place Engineering Week Student Challenge** - Awarded for presenting a research poster at UTA (2016)
- **Computer Science Engineering IAB Endowed Scholarship** - Awarded $1000 by the College of Science and Engineering, UTA (2016)
- **Startup Pitch Competition, 3rd Place** - Awarded $100 by the University of Texas at Arlington, College of Business for presenting my master's thesis project as a business idea (2016)