Evidence of Learning in Virtual Reality

A literature review

by
Endre Olsvik Elvestad

Department of Computer Science
Norwegian University of Science and Technology
Norway
10.06.2016

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Chapter 0

Introduction

0.1 Motivation and Background

Virtual reality(VR) has captured people's imagination. Over the last few years, designers, developers and enthusiasts have devoted countless hours to design, coding and exploring the possibilities of this exciting re-emergence of a long dreamt about medium. Affordable and fast hardware systems like the Oculus Rift, Samsung Gear, HTC Vive and Google Cardboard enable consumers to experience high quality VR first hand.

Virtual Reality is envisioned as the medium that will enhance the communication between humans and computers for the next decade. The ability to be transported to other places, to be fully immersed in experiences (to feel that you are really present) opens up ways to interact and communicate that previously have only been reserved for science fiction.

This new way of computer aided interaction opens up a new possibilities of human learning. Up until now teaching complex topics like medicine and engineering have been too costly or unfeasible at scale to teach directly, making us settle for an indirect approach through classroom lectures and books. The emerging availability of low-cost, high fidelity Virtual Reality Environments opens up new possibilities for direct learning that is both cost effective and scalable.

With the explosive development in the field of human-computer interaction there is a need for an effort to summarize current research on how VR Environments can affect learning, with the goal of providing a comprehensive view of the current state of the art of VR environments on learning and provide a roadmap for future study.

0.2 Goals

- G1) Providing an overview of the historical development in Virtual Reality
- G2) Providing a comprehensive overview of the technological foundations behind the current VR renaissance, both for hardware and software
- G3) Summarising current knowledge and best practice on learning in VR
- G4) Showing where more research is needed.

Chapter 1

Historic Developments in Virtual Reality

To see the future, one must look back at the past. This chapter outlines the historical development of Virtual Reality from the 1960 until mid 2000s.

1.1 Sensorama (1960-1962)

Morton Heilig created a multi-sensory simulator. A pre-recorded film in color and stereo was augmented by binaural sound, scent, wind and vibration experiences. This was the first approach to create a virtual reality system and it had all the features of such an environment, but it was not interactive.

1.2 The Ultimate Display (1965)

Ivan Sutherland proposed the ultimate solution of virtual reality: an artificial world construction concept that included interactive graphics, force-feedback, sound, smell and taste.

1.3 The Sword of Damocles (1966)

This was the first virtual reality system realized in hardware, not in concept. Ivan Sutherland constructed a device considered as the first Head Mounted Display (HMD), with appropriate head tracking. It supported a stereo view that was updated correctly according to the users head position and orientation. It used ultrasound to calculate head position and rotation making it prone to cumulative errors.

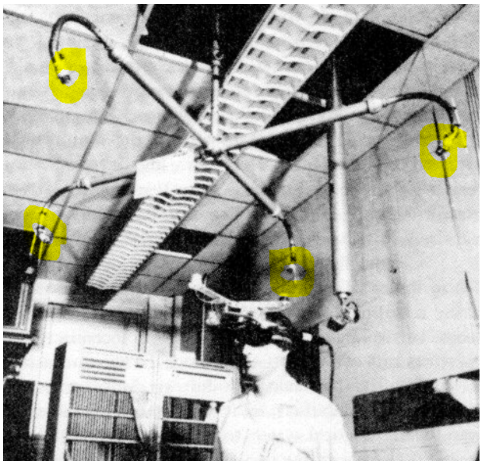

Figure 1.1: The Sword of Damocles

1.4 GROPE (1971)

This was the first prototype of a force-feedback system realized at the University of North Carolina.

1.5 VIDEOPLACE(1975)

Artificial Reality created by Myron Krueger a conceptual environment with no existence. In this system the silhouettes of the users grabbed by the cameras were projected on a large screen. The participants were able to interact one an other thanks to the image processing techniques that determined their positions in 2D screens space.

1.6 VCASS (1982)

Thomas Furness at the US Air Forces Armstrong Medical Research Laboratories developed the Visually Coupled Airborne Systems Simulator an advanced flight simulator. The fighter pilot wore a HMD that augmented the out-window view by the graphics describing targeting or optimal flight path information.

1.7 VIVED (1984)

Virtual Visual Environment Display was constructed at the NASA Ames with off-the-shelf technology a stereoscopic monochrome HMD.

1.8 VPL (1985)

The VPL company manufactured the popular DataGlove and the Eyephone HMD (1988), the first commercially available VR devices.

Figure 1.2: VPL

1.9 BOOM (1989)

BOOM is a small box containing two CRT monitors that can be viewed through the eye holes. It was commercialized by the Fake Space Labs. The user can grab the box, keep it by the eyes and move through the virtual world, as the mechanical arm measures the position and orientation of the box.

1.10 UNC Walkthrough project (1980s)

The University of North Carolina developed an architectural walkthrough application. Several VR devices were constructed to improve the quality of this system like: HMDs, optical trackers and the Pixel-Plane graphics engine.

1.11 CAVE (1992)

CAVE (CAVE Automatic Virtual Environment) is a virtual reality and scientific visualization system. Instead of using a HMD it projects stereoscopic images on the walls of room (user must wear LCD shutter glasses). This approach assures superior quality and resolution of viewed images and wider field of view in comparison to HMD based systems.

1.12 Virtual Boy (1995)

It was marketed as the first ”portable” video game console capable of displaying ”true 3D graphics”. Even though Virtual Boy proved to be a commercial failure for Nintendo it was the first ever VR experience marketed towards the general public.

Figure 1.3: Virtual Boy

1.13 VirtuSphere (2000s)

The ViertuSphere consists of a 10-foot hollow sphere, which is placed on a special platform that allows the sphere to rotate freely in any direction according to the users steps. It works with computer based simulations and virtual worlds, and rotates as the user walks, allowing for an unlimited plane upon which the user can walk.

Figure 1.4: VirtuSphere

Chapter 2

Technological Foundations for Virtual Reality

In this chapter we will look at the development of the hardware market from the launch of Oculus DE 1 until today. We then utilize this knowledge to forecast prospects for further development, focusing on Head Mounted Displays (HMD) and new input devices.

2.1 Hardware

2.1.1 Output - Head mounted Displays (HMD)

2.1.1.1 Mobile HMD

Google Cardboard
The Google Cardboard is the easy gateway to experiencing current VR applications. It is a simple low cost cardboard container for your smartphone, combined with simple optics and a magnet. The Google Cardboard can be used with almost any smartphone and uses the phone's embedded gyroscope to determine head rotation and position, sliding the magnet up or down on the side triggers a compass event that can be used in applications as a mouse click does not come with head straps and the embedded gyro is prone to high latencies, so long term use have been frequently reported to induce nausea.

Samsung Gear VR
The Gear VR is an Oculus Rift-powered device that uses a Samsung Galaxy smartphone as its processor and display. However, unlike Google Cardboard the Gear VR does not use the phone's build-in gyroscope, but a custom inertial measurement unit(IMU) that leads to

lower latency and less nausea. The Gear also uses custom Barrel distortion lenses made by Oculus that gives a more natural view and a touch control panel on the side.

2.1.1.2 Wired HMD

HTC Vive
The HTC Vive plugs into your computer and works with Valve's mammoth gaming ecosystem. It packs in over 70 sensors and offers 360 degree head-tracking as well as a 90Hz refresh rate; the stat that is key to keeping down latency. It also works in tandem with both custom controllers and motion tracking cameras creating a strong immersive experience.

Sony PlayStation VR
Sony PlayStation VR will connect to the Sony PlayStation 4. The PS4 is at the very beginning of its life cycle and its AMD graphics processor has been built to handle stereoscopic 3D processing. This enable it to render crisp and low-latency images. Currently the Playstation VR has not come on market and reviews are based on prototypes.

Oculus Rift
Oculus Rift is the virtual reality headset that started a new spring for Virtual Reality. After a hugely successful Kickstarter campaign and being bought up by Facebook for 2 billion USD Oculus has made major leaps forward. Starting at a low 640x800px resolution per eye in their first developer release to a full 1080x1200px per eye on the first consumer edition. The first full consumer edition also features 360 degree head tracking like the Vive, as well as advanced motion tracking controllers.

2.1.2 Input

2.1.2.1 Hand based

General Controller

Touch by Oculus
VR controller that accurately tracks hand movement in VR, but not motion.

Xbox one controllers
Conventional console controller

Vive Controller
Combined with the Vive sensors the Vive controller provides accurate hand tracking, but not finger tracking. Similar to a Wii controller.

Specialized controllers

Trinity Magnum
A gun shaped controller with accurate motion detection for shooting games & simulations.

Thrustmaster Warthog
Uses a combination of Joy Stick, Weel and pedals for simulation control.

2.1.2.2 Motion Capturing & Controllers

Free hand

Leap Motion
With Leap Motion, you can interact with digital content in virtual and augmented reality, Mac and PC using your hands just as you would in the real world.

Kinect
Kinect enables users to control and interact with their console/computer without the need for a game controller, through a natural user interface using gestures and spoken commands.

Perception Neuron
It captures motion through a special sensor suit placed on the arms and torso.

Vive Sensor
In combination with the Vive controller captures arm and body movements accurately from all sides.

2.1.2.3 Haptic feedback

Araig Haptic
This is a full body suit that gives haptic feedback with events in game

Dexmo
Dexmo is a mechanical exoskeleton system with force feedback for you to touch the digital world and captures your hand motion

Teslasuit
The Teslasuit is a full body haptic skin which uses anelectro-tactile feedback system to give the wearer sensations of touch, force and warmth.

2.1.2.4 Treadmills and Locomotion

Virtuix Omni
Uses a platform to simulate the motion of walking, requiring special shoes that reduce friction. It works in conjunction with the Oculus Rift or any other head mounted display and allows gamers to walk or run within the game they are playing.

Virtusphere
Virtusphere consists of a 10-foot hollow sphere, which is placed on a special platform that allows the sphere to rotate freely in any direction according to the users steps.

2.1.2.5 Other controllers:

Mind Maze
Mind Maze is a platform to build intuitive human machine interfaces combining virtual reality (VR), computer graphics, brain imaging & neuroscience. The companys medical grade technology enables new applications in gaming, brain machine control, and health care.

”Taste”
Taste is a food Simulator project at the University of Tsukuba

2.2 Software

Previous efforts to commercialise Virtual Reality on a broad scale have not only been hampered by lack of sufficient hardware, but also by costs associated with building well functioning software applications. This chapter examines the state of the current software ecosystem for Virtual Reality.

2.2.1 Game Engines

Currently all the different VR systems come with their own Software Development Kits (SDKs). These are device drivers and software libraries used in conjunction with the host operating system. Popular examples are Win32 libraries on Windows and the Android SDK.

For cross platform support and faster development many will choose to work with a Game Engine that takes care of low level 3D rendering, physics and interfacing to devices. It is important to note that Game Engines are not restricted to creating games. They are made to simulate a general 3D environment. Currently two commercial game engines actively supports VR application development and device deployment.

2.2.1.1 Unity 3D

Unity is a lightweight, low cost game engine focusing on rapid development. The Unity environment provides many important development features such as a rich material system, real time rendering and lightning, portability and a rich VR community.

Unity has traditionally not been as optimized for next-gen graphics compared to the competition, and has some catching up to do even after the release of Unity 5. However, what it lacks in graphics features is made up for by its extensive developer community. The Unity Asset store utilizes Unitys modularity to provide a vide array of models, textures, sounds and engine extensions. This enables Unity developers to use more time on the game logic and have make Unity the platform of choice for the indie developer

2.2.1.2 Unreal Engine

Unreal Engine has a larger focus on the more established industry. It provides more sophisticated lightning and rendering options and a high degree of integration with other well established industry tools. It has a steeper learning curve than Unity, with code written in C++ and fewer tutorials aimed at newcomers. Unreal Engine gives its developers access to the source code something that is essential for larger development studios. This is currently not provided with Unity.

2.2.2 Frameworks

Modern web browsers have become increasingly powerful over the years. Much due to the JavaScript API like WebGL, modern browsers are now fully capable of rendering advanced 2D and 3D graphics without third-party plugins.

Current Browser-VR solutions are all on the testing stage, but it is developing rapidly. In the foreseeable future it is possible that web frameworks in VR will provide many of the same benefits that they currently provide for mobile application development.

2.2.2.1 Three.js

Being the most mature of the current web 3D frameworks Three.js has a robust codebase and is supported by a large community. The newly deployed StereoEffect library gives easy access to typical Stereo camera options needed to render a view for both eyes, with just three lines of code a VR stereoscopic camera can be instantiated.

```
effect = new THREE.StereoEffect( renderer );

effect.eyeSeparation = 10;

effect.setSize( window.innerWidth, window.innerHeight );
```

2.2.2.2 Babylon.js

Being the creation of Microsoft and shipped in 2013 together with IE 11 Babylon is the relative newcomer of the established 3D web frameworks. At the time of this writing Babylon.js shows less developer adoption than three.js, but provides native support for Oculus and other VR devices.

2.2.2.3 A-Frame

A-Frame is an open-source framework for easily creating WebVR experiences with HTML. It wraps three.js and WebGL in HTML custom elements. Because of the broad adoption of WebGL in modern browsers across all platforms, A-Frame experiences work across desktop, iOS, Android, and Oculus Rift headsets. Since A-frame is an abstraction layer on top of Three.js, A-Frame is capable of doing anything that three.js can, but with easier access to VR specific code.

2.2.3 Configurable Virtual Environments

Not everyone can code, but many wish to design their own virtual environment. Configurable Virtual Environments are platforms where users can build their own game or simulation with minimal code or graphics development.

2.2.3.1 Second Life

Created in 2003 Second Life has a well developed platform for user created games and simulations. The platform currently has 1 million regular users and is the largest customisable virtual world. Second Life has been used extensively for research on virtual worlds and learning and human socialising in the virtual space. The platform has recently incorporated native Oculus support, but suffers from outdated graphics.

2.2.3.2 AltSpace VR

AltSpace VR is an up and coming company providing semi-customizable virtual environments and aims at being the next big social platform - One click and you are in a virtual space with people you care about. AltSpace currently works on furthering the user customisation of its platform and is as opposed to Second Life build natively for the VR environment.

Chapter 3

State of the art in Virtual Reality environments for learning

In Chapter three we conduct a systematic literature review to identify current research in the intersection of virtual reality and learning. Systematic literature reviews have their origin in medicine, and is a method of reviewing the literature around a research question in a structured manner. The goal is to raise the probability of finding all the relevant literature and structure the review in such a way as to give an unbiased conclusion. However, such reviews require increased effort when compared to unsystematic reviews due to extensive planning and logging procedures.

3.1 Introduction

When we initially analysed potential new applications arising from cheap and more available virtual reality hardware, we identified a challenge of high relevance, that is what makes up a good learning environment in Virtual Reality? This challenge is of particular importance since VR learning has been identified numerous times as one of the major applications of the new VR renaissance, and since we can thus expect a rapid growth in VR learning applications. To ensure that these applications are built- on sound research and on tested educational theories is important not only to the field of VR, but to the advancement of human learning. To the best of my knowledge no systematic review has been performed with regard to the research goals presented here after the recent renewed interest in Virtual Reality in 2016.

3.2 The Literature Review Method

This section outlines the method used to perform this systematic literature review. The method is mainly following the guidelines explained in performing systematic literature reviews in software engineering presented by Kitchenham [2007](27), but have been adjusted to fit the Virtual Reality domain. In addition to these guidelines, ideas have also been taken from the systematic review performed by Lillegraven and Wolden [2010](28). The systematic literature review process was performed in seven steps:

Step 1: Defining research questions

Step 2: Search for relevant studies

Step 3: Selection of studies

Step 4: Quality assessment

Step 6: Data synthesis and analysis

Step 7: Dissemination

In subsequent sections the purpose of performing each step, and the procedure used will be presented. The results from steps 1-4 are presented in their own section, while results from steps 5-7 are presented in chapter 3 .

3.2.1 Defining Research Questions

The purpose of defining a set of research questions is to create clarity.We seek questions that clearly have relevance for the topics of the review and that help outline the scope of the review.

Based on the goals of the review outlined in the introduction the following research questions are to be answered:

RQ1 What is the breadth of the existing solutions that aim to teach in a Virtual Reality Environment?

RQ2 How do the different solutions(found through the work with RQ1) compare to each other with regard to type of material(theoretical, practical, etc), input/output type for interacting with the environment and modes of human-computer interaction?

RQ3 What is the strength of evidence of learning outcomes in support of the different solutions?

RQ4 For studies with high strength of evidence for achieved learning, what are the common factors? Are these factors absent from studies with lower level of learning outcomes?

RQ5 What implications will these findings have for creating future learning environments in virtual reality?

3.2.2 Search for Relevant Studies

This section explains the methodology used to find relevant studies for the review. The goal is to retrieve the available literature relevant to answer the chosen research question. The search strategy for the review consisted of two steps. Firstly, developing an overview of relevant sources likely to contain studies relevant for the review. Secondly, developing search terms to further narrow down the search to yield informative studies.

To create the list of sources we searched through the relevant digital libraries presented in studies by Kitchenham [2007](27) and Dybnd Dingsøyr [2008](29).

Source	Type
ACM Digital Library	Digital library
IEEE Xplore	Digital library
Web of Knowledge	Digital library
Wiley Inter Science Journal Finder	Digital library

Table 3.1: Data Sources

For locating relevant studies in the data sources a set of keywords grouped together has been used where the groups form logical entities related to our research questions and the terms in the groups are synonyms .

Table 3.2: Key Words

	Group 1	Group 2	Group 3
Term 1	Virtual Reality	Teaching	Virtual Environment
Term 2		Learning	Simulation
Term 3	Oculus Rift	Pedagogy	
Term 4	Google Cardboard		

Manual searches were done by browsing the titles of studies and reading the abstracts when possibly relevant articles were found. If the study seemed promising it was included in further stages.

Search results:
The results from the search phase are presented in the table below.

Source	Type
ACM Digital Library	203
IEEE Xplore	190
Web of Knowledge	259
Wiley Inter Science Journal Finder	58

Table 3.3: Search results

3.2.3 Selection of Studies

The goal of the study selection process was to filter down the studies found in the search stage to form a set of studies that were able to answer the study's research questions and which also presented research of high quality.

The studies from the search phase have been evaluated based on the following criterion.

- The studys main concern is Learning in a virtual environment
- The study is an empirical study presenting empirical results
- The study seeks to evaluate some aspect of learning in a simulated environment
- The study uses Virtual Reality as a basis for the simulation

If the study fulfilled all the evaluation criteria it also got evaluated on the following quality criteria:

- Is there a clear statement of the aims of the research?
- Is the study related to other studies and research in the field?

Finally, if a study passed all evaluation and quality criteria, it was included in the review.

3.2.4 Quality Assessment

To evaluate the strength of the evidence presented by studies included in the this review each study was assessed for its quality using the following criteria.

- Is the decision of using virtual reality as a test environment justified?
- Are the elements of the virtual environment explained sufficiently to be reproducible?
- Is the experimental procedure thoroughly explained and reproducible?
- Are the performance metrics used in the study explained and justified?
- Are the test results thoroughly analysed?
- Does the test evidence support the findings presented?

The first two criteria have been assessed earlier, so the final six quality questions were performed at this stage in the review. If a given study satisfied more than 3 out of the 6 additional quality questions, it did get included in the review

3.2.5 Data Collection, Synthesis and Analysis

When the study passed through this quality assessment phase, it was collected, categorised and analysed. The following strategy for the synthesis and analysis of the results was applied:

1. Sort the studies included in the review into solution types according to what aspect of learning is being studied
2. Answer our research questions presented in Section 3.2.1
3. Group studies with similar approaches and outcomes
4. Analyze in detail sets of papers that have similar approaches, but conflicting conclusions.

All four stages were performed on the studies found in table 3.3. The analysis led to findings which were logged during the review. The findings are presented and discussed in Chapter 4.

3.2.6 Dissemination

The primary reporting of the review is this project thesis. In addition, it will be publicly available on Researchgate and Github.

Chapter 4

Results

In this chapter the results of the systematic literature review of building Virtual Reality applications for human learning are presented. The chapter presents first an overview of the studies included for review and analysis, before moving on to structuring the different dimensions of a Virtual Reality learning system. Finally, in section 5.3.2 a summary of key points from the included studies are evaluated along these dimensions.

4.1 Studies Included in this Literature Review

As reported in Section 4.2.3 the result of the literature search and selection process resulted in 21 relevant studies for inclusion in this review.

4.2 Challenges when building VR applications for Learning

This section first presents a framework for categorizing the different dimensions of a Virtual Reality Learning application. The dimensions are drawn from experiences presented in the papers included in this review and will work as guidelines for comparing different approaches and tying these to their learning outcomes. Finally, this section summarizes the studies included in this review as appertaining to the evaluation framework.

4.2.1 Learning Dimensions - A proposal for an evaluation framework for Educational VR

Good Virtual Reality applications come in all shapes and sizes. From high fidelity simulations with premium hardware to simple games using a Smartphone put into a cardboard box. Software wise VR learning applications have a lot in common with VR games, but they differ in that they convey knowledge to the user.

Given this fact one cannot conclude that since one type of application has shown good learning results, all applications using the VR medium provide good learning outcomes. The challenge then becomes to find the dimensions of a Virtual Learning Environment (VLE) that are important for learning, so that we can compare VLE and give sound evaluations on best practices for developing future solutions that create good learning outcomes.

This literature review has taken the bottom-up approach to create an evaluation framework using the relevant studies as a basis for extracting relevant evaluation criteria and features of Virtual Learning Environments. The findings and rationale are presented below.

4.2.1.1 Knowledge Type

We see two main categories of knowledge types presented in the VLE solutions in this review: those that try to teach abstract knowledge such as math and English and those that teach psychomotor skills such as tennis or surgery. This is an important difference in VLE since a virtual environment is confined to three dimensions and is good at simulating the physical world, but that does not necessarily help in conveying more abstract thoughts and concepts that have no tangible parallels to a physical environment.

In the classification of learning solutions evaluated in this study knowledge type is denoted by the broad category of knowledge that the field represent, since a majority of the solutions cannot be described as an absolute (abstract or psychomotor), but is placed as a continuum along a scale.

Figure 4.1: Knowledge Type

4.2.1.2 Level of human interaction

Several of the VLE reviewed show different approaches towards human-human interactions. Applications that take an individual or a group approach seem to differ greatly in their simulation dynamic. This begs the question of the learning evidence for both these approaches and comparing them both against each other and internally.

In the classification of learning solutions evaluated in this study the level of human interaction is defined as Individual (N=1), Small group (1 <N <10), group (N >10, classroom size).

Figure 4.2: Level of human interaction

4.2.1.3 Level of human-computer interaction

Similar to the difference between VLE in human to human interaction they also differ in their usage of human-computer interaction.

Figure 4.3: Level of human-computer interaction

4.2.1.4 Learning Strategies

Historically there has been a great debate amongst educators as to what pedagogy that is most fitting to facilitate learning. There is an agreement that there is no one fits all solution, but rather that each approach is useful towards different ends. It is therefore interesting to find out what seems to fit best with VLE.

In the classification of learning solutions evaluated in this review learning strategies are described by being mainly constructivist or behavioral focused. However, it is important to note that some solutions, like simulations, do not follow either approach (Origo) and most fall as a vector between the axis .

Figure 4.4: Learning Strategies

4.2.1.5 Type of Input/Output

Virtual Reality is mediated through computer hardware and software. To find out which form of input and output that a simulation uses, is therefore interesting to look at. To what extent do HD graphics and haptic feedback play a role in learning immersion?

In the classification of learning solutions evaluated in this study the type of input/output is defined as low immersion (VR-world, 2D view, some novel input) or immersive (novel input such as haptics and kinect and output in the form of HMD or similar)

4.2.2 Evaluating Learning Outcomes

Evaluating the utility of different teaching methods has been a long standing debate. Even more so when there is a need to objectively talk about the depth of learning that a given teaching method achieves. This review uses Blooms Taxonomy as the basis for evaluating learning outcomes in virtual reality. Blooms Taxonomy is described as a method of classifying educational objectives, educational experiences, learning processes, and evaluation questions and problems (1). It provides the basis for many contemporary evaluation techniques and is connected with other concepts such as creative and critical thinking, problem solving skills, and the theory of multiple intelligences.

Bloom classifies human thinking into six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation which later on were changed to correspond to remembering, understanding, applying, analyzing, evaluating and creating.

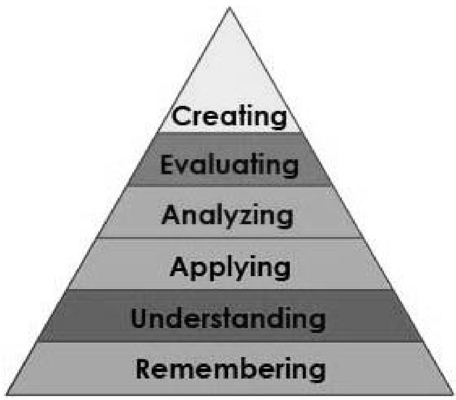

Figure 4.5: Evaluation of learning

In this study we evaluate strength of learning as to:

1) What level of the Blooms Taxonomy is achieved in the study?

2) What is the degree of certainty attained by the study's results?

4.3 Range of Existing Applications of VR for learning

This section explores the existing solutions in more detail. For each dimension in the framework presented in 4.2.1 we will show case approaches that are on opposite sides of the spectrum by highlighting the broad landscape of different approaches within the Virtual Reality Learning space.

4.3.1 Knowledge Type

4.3.1.1 Mathsigner(2)

Mathsigner is a Virtual Reality Learning Environment for teaching deaf children mathematics. Through a fantasy 3D world consisting of a candy and a clock store filled with imaginary bunny characters the pupil learns to think mathematically and communicate mathematical concepts through sign language. The program can be displayed on numerous immersive devices and includes motion tracking gloves as well as six-degree-of-freedom wrist tracker. This enables the user not only to learn sign language from the imaginary bunnies, but also to communicate directly with the animated characters.

4.3.1.2 SonoTrainer (3)

Few simulators have been formally studied to date. The SonoTrainer ultrasound simulator has been examined for its potential in training surgical residents in interpreting ultrasound images for screening of fetal abnormalities. Investigators concluded that it was as effective as live patient training, but more convenient and scalable.

4.3.2 Level of human interaction

4.3.2.1 Upper extremity stroke recovery(4)

In 2008 a study on novel treatment programs for upper extremity-related motor functioning in subacute stroke patients developed an Playstation Eyetoy system to help in movement control. The study revealed that patients showed significant improvement in motor functions when using the system in addition to conventional rehabilitation programs. The user is playing individually and the game adapts to the user's current level.

4.3.2.2 Spokane Research Laboratory(SRL): Fire escape training for mine workers (5)

SRL has developed a Virtual Reality Training program that allows groups of four trainees to work together in a virtual world via a computer network to practice fire prevention and evacuation routines. A recent evaluation of the system showed that it provides good learning outcomes for teaching mine fire prevention, not only is it safe and reliable, but it can achieve the expected training objectives and reduce the costs greatly.

4.3.3 Level of human-computer interaction

A meta study looking at the effectiveness of VR based instruction found significant differences in learning outcome based on type of human computer interaction (6). Dividing the degree of computer interaction into three parts.1) Simulations allow learners to test their hypotheses of the effects of input variables on the intended outcomes.(7) 2) Contrary, to the structured environment of simulations and games, virtual worlds are open-ended environments in which users design and create their own objects.(8) 3) Games must in addition to a simulation be designed to provide players with a sense of autonomy and identity.(9)

4.3.3.1 V-Frog (10)

V-Frog is a virtual reality based frog dissection simulation designed for biology education. The student can pick up a scalpel, cut and open the skin of the frog and explore its anatomy and physiology, just like what he/she would do with a physical frog.

4.3.3.2 River City Project (11)

River City is a Virtual Learning Environment set in a town troubled with health problems. Students work together in small research teams to help the town understand why residents are becoming ill. Students use technology to keep track of clues that hint at causes of illnesses, form and test hypotheses, develop controlled experiments to test their hypotheses, and make recommendations based on the data they collect. The project aims at teaching middle schoolers scientific thinking and creative problem solving.

4.3.3.3 DimensionU (12)

DimensionU is comprised of four multiplayer games and aims at teaching both math and literacy for primary school pupils. Each game is designed around the principle of gamification to bring out distinct academic and strategic skills in students.

4.3.4 Learning Strategies

4.3.4.1 Triage Trainer(13)

Triage Trainer is a VR application aiming to improve the accuracy in applying the triage protocol (degree of need for emergency care). It is used both for first time training and to prevent that skills fade for more experienced practitioners. Triage Trainer utilizes adaptive feedback evaluation for increased retention. The more skill a student shows in a specific task, the less feedback is provided. This adaptive evaluation is independent of past experience and is only depended on the learner's choices in-game. As such the system prevents teaching bias and a experienced surgeon can get more frequent feedback than a student for a given task.

4.3.4.2 Roma Nova

Roma Nova is a virtual simulation set during the height of the Roman Empire. It is a serious game which enables exploratory/constructivist learning by immersing the user in a virtual environment where they learn different aspects of Roman history through their interactions with a crowd of virtual authentic Roman characters.

4.3.5 Type of Input/Output

4.3.5.1 Cerebral Aneurysm Clipping Simulation

Using the Immersive Touch platform the cerebral aneurysm clipping simulator provides real-time sensory haptic feedback- giving the student not only an immersive visual and auditory experience, but also a realistic haptic feedback response while performing the virtual surgery.

Figure 4.6: Cerebral Aneurysm Clipping Simulator

4.3.5.2 Heliflight-R Flight Simulator (15)

Heliflight-R is a modular full motion capsule for high fidelity helicopter training. It provides a realistic motion and visual picture of a real helicopter and can be adapted to simulate several different chopper types. The added motion realism gives the user the possibility to train on different emergency procedures such as rolling and motion blindness, where you is expected to trust the sensors above your own senses.

Figure 4.7: Heliflight-R Flight Simulator

4.4 Analysis

This section first compares our different VR applications against each other with respect to the evaluation framework described in 4.3. Then we move on to evaluate the strength of evidence for learning given by our evaluated studies.

4.4.1 Comparison of Solutions

This section presents an overview of how the different Immersive Virtual Learning Environments compare to the evaluation framework. The strength of evidence evaluate the learning outcome based on Blooms Taxonomy and ASPS Rating scale for grading strength of evidence in medical studies.

Table 4.1: Comparison of VR solutions

Name	Knowledge Type	Level of human interaction	Level of human-computer interaction	Learning Strategies	Degree of Immersion	Strength of evidence for learning, & Blooms taxonomy level	
Mathsigner	Language Learning	Individual - No human-human interaction	Virtual Environment	Behavioral with little creative freedom	Full immersion. HMD & pinch gloves	Initial tests with a small sample group showed positive results in,mathematical understanding and application compared to traditional methods.	Understanding & application
SonoTrainer	Medical diagnostic	Individual	Simulation	Behavioral	Full immersion. Realistic ultra sound scanner w/dummy	45 persons divided into test & controll group showed significant improvement in application and analysis with a 95% confidence.	Application & analysis
Upper extremity stroke recovery	Stroke Recovery	Individual or small group	Game	Behavioral	Some degree of immersion. 2D screen + full body gesture control	20 patients showed significant recovery improvement over the control group after 4 weeks of training	Regained mobility
SRL: Fire escape training for mine workers	Safety Training	Small group	Virtual Environment	Constructivist	Low degree of immersion. 2D screen + co-location of the participants	Small sample size showed a 37% time improvement in completion of more complex scenarios.	Evaluation
V-Frog	Anatomy	Individual or small group	Game	Behavioral	Low degree of immersion	Students using V-frig surpassed a control group doing a normal dissection both immediately and,a later retention test.	Understanding
River City Project	History/creative problem solving	Individual or small group	Game	Constructivist	Adaptable	Inconclusive. Possibly better for kinetic and visual learners.	Creating, Evaluating

Table 4.2: Comparison of VR solutions 2

Name	Knowledge Type	Level of human interaction	Level of human-computer interaction	Learning Strategies	Degree of Immersion	Strength of evidence for learning, & Blooms taxonomy level	
Triage Trainer	Medical Emergency Triage	Individual	Simulation	Behavioral	Adaptable	Students taught using the seriousgaming method are significantly more likely to accurately triage allthe casualties using the triage sieve correctly.	Analysising, evaluating
Roma Nova	History	Individual	Virtual Environment	Constructivist	Adaptable	Assessment on going. Initial findings promising	Understanding
Cerebral Aneurysm Clipping Simulation	Medical Surgery	Individual	Simulation	Behavioral	High degree of immersion w/ haptic feedback	Neurosurgical residents thought that the immersive VR simulator is helpful in their training, especially because they do not get a chance to perform aneurysm clippings until late in their residency programs.	Evaluating
Heliflight-R Flight Simulator (15)	Flight training	Individual	Simulation	Mixed	High degree of immersion w/video sphere and eye tracking.	Conflicting results for new pilot training. Positive results for training experienced pilots on uncommon scenarios	Analysis, Evaluating
VisualizeR(16)	Anatomy	Individual	Virtual Environment	Constructivist	Adaptable. HMD support	Study show a high degree of satisfaction compared to conventional textbooks.	Understanding

Table 4.3: Comparison of VR solutions 3

Name	Knowledge Type	Level of human interaction	Level of human-computer interaction	Learning Strategies	Degree of Immersion	Strength of evidence for learning, & Blooms taxonomy level	
VR English language learning platform(17)	Language	Individual	Virtual Environment	Mixed	High degree of immersion	Results show that students improved their phonological, morphological, grammar and syntax knowledge.	Applying
Second life for illiterates: a 3D virtual world platform for adult basic education(18)	Reading/writing for adults	Individual or group	Virtual Environment	Mixed	Adaptable	Inconclusive results found from a small test group.	Applying, analysis
SMILE(19)	Deaf education	Individual	Game	Behavioral	Adaptable	High user enjoyment. Learning outcomes to be assessed.	Understanding
Spatial learning: cognitive mapping in abstract virtual environments(20)	Cognitive mapping	Individual	Virtual Environment	Constructivist	High degree of immersion	Negative. Users scored worse,compared to conventional methods	Understanding

4.4.2 Strength of Evidence

In this study, the learning achieved by a virtual reality solution is measured by the development of knowledge, skills, comprehension, simulation, application, and creativity in accordance to the teaching objectives that have been set and the taxonomies for students learning outcome proposed by Bloom and Anderson(22). Furthermore, where data for comparison of learning gains against traditional methods is available then this is considered as an indicator of usefulness for learning.

4.4.2.1 VR as a Learning resource

In the VR solutions studied in this review 13 out of 15 showed evidence of learning and 10 of 15 showed significant gains compared to traditional methods. This is consistent with findings by Larsen et al(2012) for medical simulations which concludes that There is strong evidence to suggest that virtual reality simulators can support both training and assessment in laparoscopy.(23) In this review we conclude that there is a strong degree of evidence that VR is a suitable learning tool in a vide array of learning types.(26) (25) Furthermore, that VR learning solutions can work across all levels of Blooms taxonomy. In our sample a high percentage of the studies focusing on Blooms analysis and evaluation levels. A Theory is that this is due to the prevalence of cheep learning material for the remembering and understanding levels that makes VR too costly. For the highest level, creating, one may have the same effect, where the creation of large scale open environments are too costly. Alternatively, such open application may takes on different forms and not be labeled as a learning solution. The popular game Minecraft that can be thought of as a virtual lego-playground is labeled a game, but is often praised for facilitating creative problem solving and learning.

4.4.2.2 VR as a facilitator for collaborative learning

In a digital world where MMORPGs(Massive Multiplayer Online Role Playing Games) like World of Warcraft and online cooperation games such as Borderlands are hugely popular and regularly played by millions, one would think that VR applications would be a great facilitator for collaborative learning. However, 10 out of 15 applications are exclusively made for the individual. All but one has an individual option combined with multiplayer. Of the 15 examined solutions 14 provide single-player in some form. Even though the one solution that is exclusively group based showed good results one cannot conclude that VR at present is a good medium for collaborative learning.

This however should not discourage, but rather encourage future experiments with collaborative VR learning environments. There is certainly some promising evidence to suggest that interaction with another person during the use of computer-based tasks significantly improves learning outcomes. For example, Mevarech et al. (1991) found that, when children worked in pairs on computer-based tasks, they were significantly more likely to demonstrate improvements in learning compared to children who worked individually.(21)

4.4.2.3 VR as a real world substitute

10 of the 15 VR solutions are aimed towards teaching activities that is enacted in a real world 3D environment. Many of which would expose either the learner(Fire escape, helicopter maneuvering) or a third party(surgery patient) to possible harm. The remaining solutions enact the world as it was(history) or simulate interactions(Sign language(19), autism(25)). There is strong evidence that VR induces a real world immersion and facilitate a type of learning the learner feels confident transferring these skills into the real world.(23) (6) (9) (24)

4.4.3 Conclusion

This literature review describes the application of virtual reality technology to facilitate learning and introduces a framework to compare different types of learning methodologies and virtual environments. It then proceeds to draw conclusions from previously studies VR learning solutions. The conclusions are as follows.

1. There is strong evidence for that Virtual reality is a good platform to facilitate learning for the individual.
2. Virtual Reality environments opens up new possibilities for learning where it previously have been too expensive or dangerous before.
3. Virtual Reality learning environments can provide learning along all the stages in Blooms Taxonomy. However, it seems at present that it is especially focused on analysis and evaluation levels.
4. Virtual reality learning environments have the highest comparable learning gains as compared to traditional education in areas that involve 3D spacial understanding. (i.e VR is superior to books when learning to sign language, but not necessarily better when learning to compose music).

Based on these findings educators should seek to adopt and integrate virtual reality learning solutions into their teaching. Methods of Human-Computer interaction in Virtual Reality with regards to learning should be further explored.

4.4.4 Limitations of this Review

The literature in the area of learning and skills development with the use of Virtual Reality environments is sparse and varies in quality. Also there is a lack of common standards for testing and evaluating knowledge gain as compared to other teaching methods. A more developed framework on how to compare different learning approaches(i.e VR against classroom learning) would increase the academic level of educational research.

Furthermore, the recent rapid changes in VR hardware and software has lead to an explosion of new VR learning applications. These are so recent that there is no published works evaluating their potential for learning, and as such is not a part of this review.

4.4.5 Focus for further study

Learning is complex, and multifactorial. This review have investigated the efficacy of VR training across a range of disciplines. There is still not enough data to show what makes ”Best Practice” when designing an VR learning solution. Future studies should be conducted to to further inform good design decisions for virtual learning environments and uncover interesting interaction effects of design features in Virtual Reality.

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