# A systematic review of Virtual Reality in education

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**Abstract.** Virtual reality has existed in the realm of education for over half a century. However, its widespread adoption is still yet to occur. This is a result of a myriad of limitations to both the technologies themselves, and the costs and logistics required to deploy them. In order to gain a better understanding of what these issues are, and what it is that educators hope to gain by using these technologies in the first place, we have performed both a systematic review of the use of virtual reality in education, as well as two distinct thematic analyses. The first analysis investigated the applications and reported motivations provided by educators in academic literature for developing virtual reality educational systems, while the second investigated the reported problems associated with doing so. These analyses indicate that the majority of researchers use virtual reality to increase the intrinsic motivation of students, and refer to a narrow range of factors such as constructivist pedagogy, collaboration, and gamification in the design of their experiences. Similarly, a small number of educational areas account for the vast majority of educational virtual reality implementations identified in our analyses. Next, we introduced and compared a multitude of recent virtual reality technologies, discussing their potential to overcome several of the problems identified in our analyses, including cost, user experience and interactivity. However, these technologies are not without their own issues, thus we conclude this paper by providing several novel techniques to potentially address them, as well as potential directions for future researchers wishing to apply these emerging technologies to education.

**Keywords:** virtual reality, education, human-computer interaction

## Introduction

Virtual reality (VR) is not a recent technology, nor is its application to education. The first recorded implementation of a digital VR system appeared in the 1966, in the form of a flight simulator designed for training purposes for the United States air force (Page, 2000). Applications remained primarily limited to the public sector for several decades, until in 1991 a series of specialized arcade games were released by the company Virtuality Group (Kushner, 2014; West, 1995). However, these proved to be unpopular and were discontinued two years later (West, 1995). In 1993 SEGA designed a virtual reality head-mounted display (HMD) and several game studios designed software for it, however it was never released (Horowitz, 2004). In July 1995 Nintendo released their own VR based game system, the Virtual Boy (Kushner, 2014). Shipping with both a controller and a monochromatic HMD, this too proved to be a commercial flop; and was discontinued less than 6 months after its initial release date (Kushner, 2014). In short, the history of commercial VR systems has thus far largely been one of failure.

Although commercially unsuccessful, numerous studies of VRs use in education yielded positive findings, ranging from increased time-on-task (Huang, Rauch & Liaw, 2010; Johnson et al., 1998), to enjoyment (Apostolellis & Bowman, 2014; Ferracani, Pezzatini & Del Bimbo, 2014), motivation (Cheung et al., 2013; Jacobson et al., 2005; Sharma, Agada & Ruffin, 2013), deeper learning and long-term retention (Huang et al., 2010; Rizzo et al., 2006).

Despite these positive results, VR systems have also failed to gain widespread adoption in education.

In this paper, we attempt to gain a better understanding of the issues faced by educators who are attempting to use VR. However, before we can understand what problems exist with VR in education, it is first useful to understand why educators choose to use it in the first place. To this end, over the course of this paper we perform two separate thematic analyses. The first investigates the applications and motivations provided by authors in scientific literature who have designed and implemented educational VR systems. Furthermore, the ways in which VR was applied by these authors was simultaneously analyzed. In a second analysis we investigate the issues and limitations reported by the authors of these systems. However, only papers that contained evaluations considering usability factors were included for this analysis. This paper is structured according to the results of the analyses performed; whereby its respective sections directly correspond to the themes and characteristics identified in the thematic analyses.

The final section of this paper introduces a range of new and upcoming VR-related peripherals, many of which have been the focus of recent mainstream media attention both for the fact that they are almost all crowd-funded, and that they aim to bring VR to the masses (Avila & Bailey, 2014; Control-VR, 2014; Cybreth, 2013; Oculus, 2012; Omni, 2014; PrioVR, 2014). We do so in order to discuss the potential this latest iteration of technologies have to overcome the various problems identified in our analyses. To aid in this process a Virtual Reality Peripherals Matrix has been tabulated, displaying the modalities, functionalities and specifications of many of these emergent technologies in a simple format. Special attention is paid to the resurgence in VR head-mounted displays (HMDs), and the unique interaction difficulties and requirements they possess (especially in terms of educational applications).

To conclude the paper, we discuss how these emergent technologies possess limitations of their own, and provide examples of future directions for educational researchers looking to overcome them.

## Methodology

Before reviewing VR educational systems, we must first clarify both what we mean by a virtual reality as well as the scope of educational systems included in this paper. While exact definition of what constitutes virtual reality vary, most definitions describe (minimally) a digital representation of a three dimensional object and/or environment. In order to capture as many relevant papers as possible, we too have adopted this broad definition, and included VR systems using any form of input/output peripheral. Resultantly, our analyses focus on literature containing over 20 different types of input and output peripherals (including traditional PC interaction).

In this paper, we also introduce a range of new and developing VR technologies, the functionalities and specifications of which are contrasted with those identified in our analyses. Thus, given the rapid rate in which changes are seen (and specifications improve) in this area, for comparisons sake we focused our review on recent research.

Mikropoulos & Natsis (2011) performed a similar review of the use of VR in education between 1999 and 2009. This research, combined with the aforementioned rapidly changing nature of this area, motivated our decision to finalize our search period to include all papers published from 2010-present (June 2017 at the time of writing).

We conducted a systematic review following the process outlined by Kitchenham (2004), and searching the academic databases ACM Digital Library, IEEE Xplore, Web of Science, ERIC, and Scopus. From this, 379 candidate papers were identified for further analysis (see Table 1).

For our initial thematic analysis (into the applications and motivations of VR in education) our inclusion criteria specified that a paper would only be included for further analysis if it had implemented a VR based solution in an educational context. Moreover, the authors must have clearly expressed their motivations behind and/or justifications for utilizing VR for the system.

To be included in the second analysis (investigating the problems with such systems) our inclusion criteria specified that the paper must have similarly designed and implemented a VR educational system, as well as performed an evaluation of it; with at least some consideration given to usability factors.

Papers that failed to express their motivations could however potentially be included in the second analysis, while those that did not perform an evaluation could be included in the first. A larger number of papers expressed the motivations behind their system than those that included an evaluation considering usability factors (90 vs. 35). 26 papers included their motivations and an evaluation, and were thus included in both of the thematic analyses performed (corresponding to 'Reoccurring Papers' in Figure 1).

**Table 1. Systematic Review Sources: Search databases, strings, and number of results**

| Database | Search String | Results |
|---|---|---|
| **ACM Digital Library** | acmdlTitle:("virtual reality" VR) AND acmdlTitle:(classroom school education) | 15 |
| **IEEE Xplore** | (("Document Title":"virtual reality") OR ("Document Title":VR)) AND (("Document Title":education) OR ("Document Title":classroom) OR ("Document Title":school)) | 39 |
| **Web of Science** | Title:("Virtual reality" OR "VR") and Title:"(education OR school OR classroom) | 128 |
| **Scopus** | TITLE ("virtual reality" OR vr) AND TITLE (education OR school OR classroo m) AND PUBYEAR > 2009 | 179 |
| **ERIC** | ((title:"virtual reality") OR (title:"VR")) AND ((title:"education") OR (title:"school") OR (title:"classroom")) | 18 |
| | **Total** | **379** |

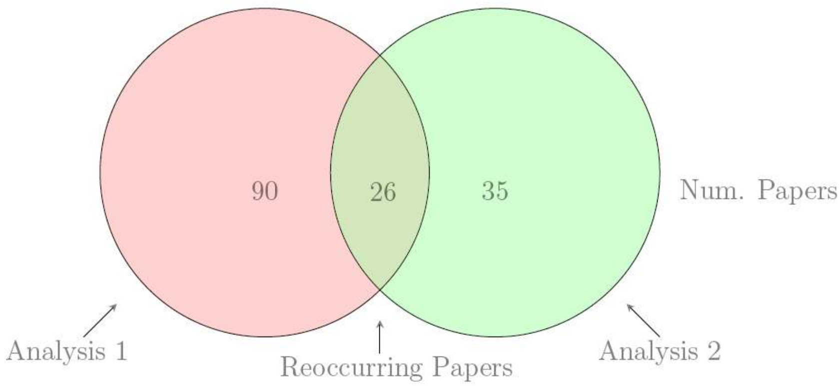


**Figure 1. Paper distribution per thematic analysis. Analysis 1 (applications and motivations of) and Analysis 2 (problems with) virtual reality in education**

These thematic analyses coded papers according to their common features (i.e. reported issues and motivations). As commonalities and trends became increasingly evident in the data these characteristics or 'codes' were in turn categorized into overarching themes. These themes resultantly form the basis for the structure of the sections that follow.

The classification data (i.e. themes and codes) from our thematic analyses were then extracted and tabulated in Figures 5 & 8; the contents of which were then discussed in further detail (with examples from the papers) in the corresponding subsections that follow.

Full versions of the tabulated data obtained from both analyses have been included in the Appendix (see Figurew 9, 10 and 11).

## Results

### *Application domains*

Before performing our initial analysis into what it is that educators hope to gain by using VR in education, we first investigated the areas to which VR was being applied - and by whom. Thus, in this section we report on the distribution of both the application domains of the papers analyzed, as well as the institutions for which they were created.

A total of 99 papers implementing educational VR software have been analyzed over the course of two thematic analyses in this paper. The implementations analyzed in these papers have been applied to 40 application domains (see Figure 4). Papers could potentially belong to multiple domains, for example, a paper could be both intended to teach Safety practices while being designed for the Construction industry. Thus, in total the 99 papers were applied to the 40 application domains 125 times. Several application domains were notably more prevalent. These include applications relating to health, engineering, science and those created to act as general-purpose educational tools (see Figure 2).

Of the 99 papers analyzed, 35 were applied to health related domains. Of these applications, 17 related to general medical topics (Falah et al., 2014; Moro et al., 2016; Schwaab et al., 2011), 10 to surgical education (Huang, Liaw & Lai, 2016; Wiecha, et al., 2010; Yoshida et al., 2014) and 3 to physical education (Song et al., 2012; Staurset & Prasolova-Førland, 2016; Zhang & Liu, 2012).

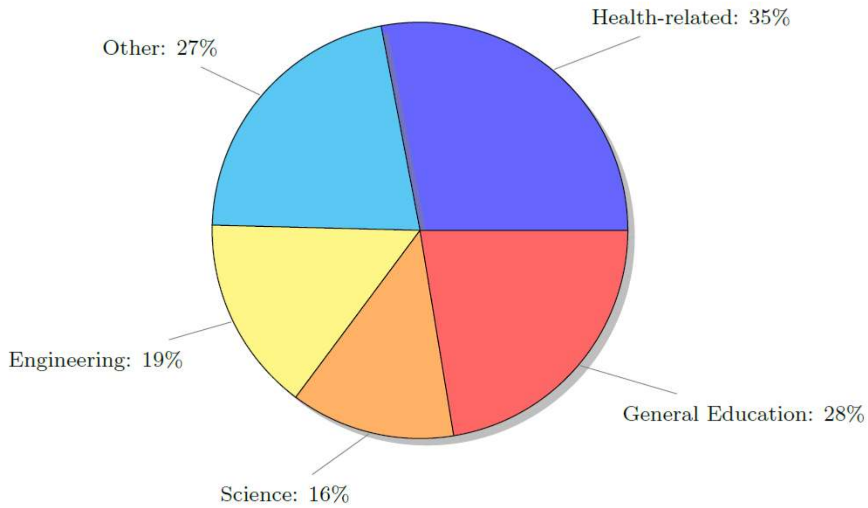


**Figure 2. Application domains of the 99 papers analyzed over the course of two thematic analyses. Note that a paper could potentially belong to multiple application domains**

Applications in engineering were also common, occurring in 19 of the 99 papers. These primarily included applications to aviation (Rupasinghe et al., 2011; Sharma & Otunba, 2012; Wei, Dongsheng & Chun, 2013), architecture (Zita Sampaio & Viana, 2013), robotics (Buiu & Gansari, 2014; Galambos, Baranyi & Rudas, 2014; Hurtado, Valerio & Sanchez, 2010), as well as several other niche areas of engineering.

Interestingly, 3 of the papers created systems designed purely for potential use in museums (Angeloni et al., 2012; Apostolellis & Bowman, 2014; Hsieh, Wub & Mac, 2010). Apostolellis & Bowman (2014) justify their VR system by stating that groups visiting museums typically do not get enough time with its content, and often simply receive information passively from museum docents. As an alternative approach, they developed a VR based collaborative and interactive environment to foster greater engagement with the museum content.

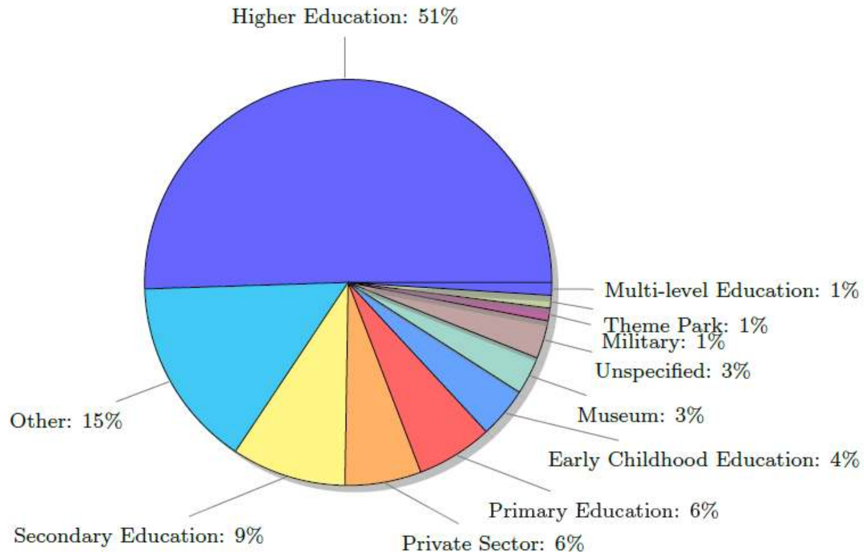


**Figure 3. Educational institutions and areas of VR applications in the 99 papers analyzed**

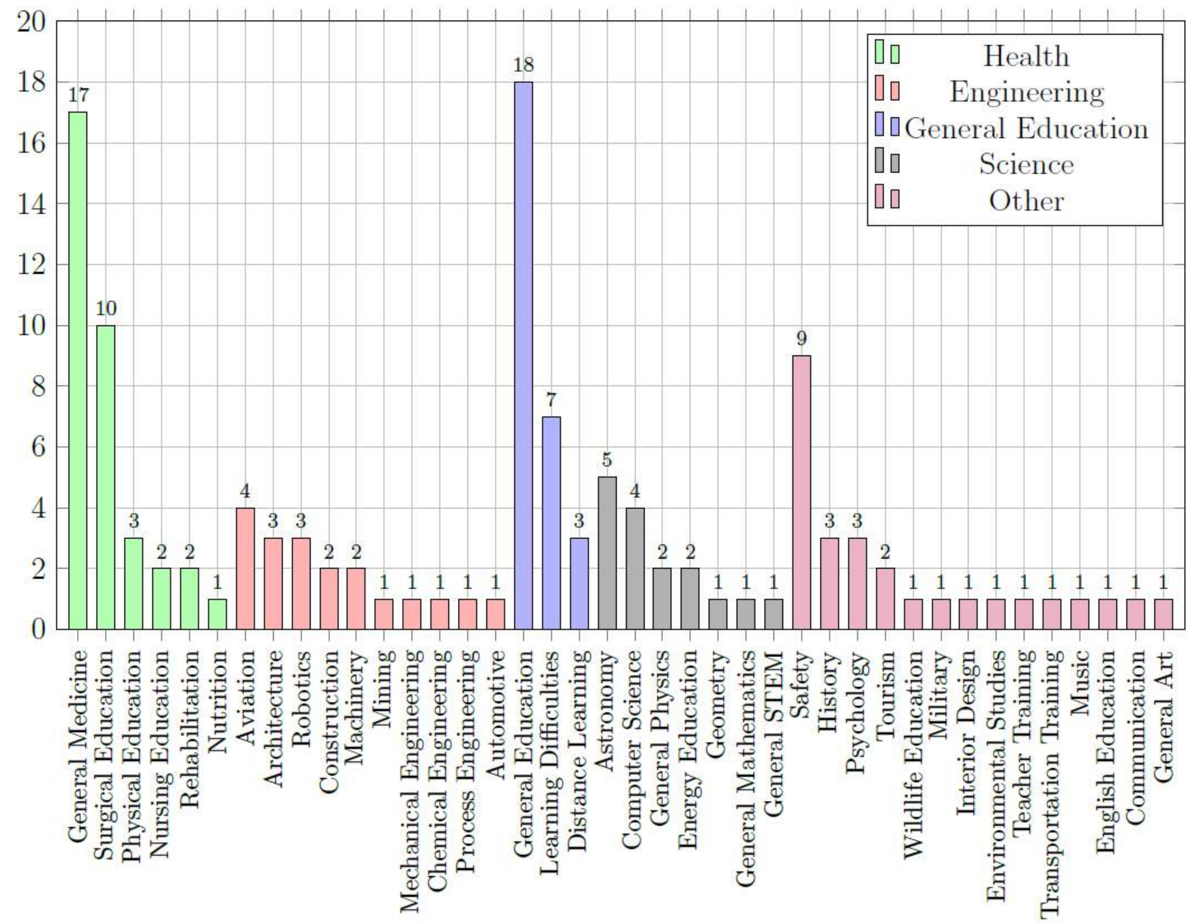


**Figure 4. Application Domain Breakdown. The individual application domains of 99 papers implementing virtual reality in education**

A total of 28 of the implementations described in the literature were not designed for any specific application domain, but were instead general tools that could be applied to various levels and areas of application (Ewert, Schuster, Johansson, Schilberg, & Jeschke, 2013; Hsiaoa, Lia, & Lanb, 2010; Kiss, 2012). Hsiaoa et al. (2010) for example designed a virtual campus using Second Life. This campus could be used by any educators wishing to teach online lessons in any area.

The use of VR in art-related subjects (i.e. literacy, visual art, music etc.) was less frequent than its use in STEM-related areas. Only 7 papers were designed to be applied to areas relating to the arts. These included implementations intended for application to music (Gomes et al., 2012), English (Chung, 2012), history (Chien et al., 2012; Fabola & Miller, 2016; Perez-Valle & Sagasti, 2012), and interior design (Meggs, Greer & Collins, 2012).

### *The applications and motivations of virtual reality in education*

This section describes a thematic analysis of 90 papers which describe the use of VR in education. We identify the common motivations for using VR, and the applications to which VR has been applied. The themes identified in the analysis are discussed in further detail in the corresponding subsections that follow.

### *Thematic analysis results*

Our initial thematic analysis of the applications and motivations of VR in education identified 13 common characteristics/codes across the papers, which could be divided between three themes and fell into one of two primary categories (see Figure 5).

The motivation-related codes identified in the literature can primarily be categorized as being either Pedagogical or Intrinsic factors. Motivations are classified as Pedagogical Factors if it was stated by the authors that their work was supported by, or designed around facilitating the beliefs of a pre-existing pedagogy. The Intrinsic Factors theme encompasses all motivations rooted in the belief that the system would result in a more positive internal or personal learning experience for the user than what is traditionally available (Huang et al., 2010).

Some papers fall into multiple categories. For example, VR implementations that allow distance learning are an area of application; however, the desire to facilitate deeper learning is an intrinsic motivational factor. The remainder of this section discusses and elaborates on the codes and themes identified in this analysis.

### *Applications*

This section outlines the applications of the VR implementations described in the literature analyzed. By *applications*, we refer not to the application domain of the implementations (which are discussed above), but to its actual purpose or *use* (e.g. to facilitate distance learning).

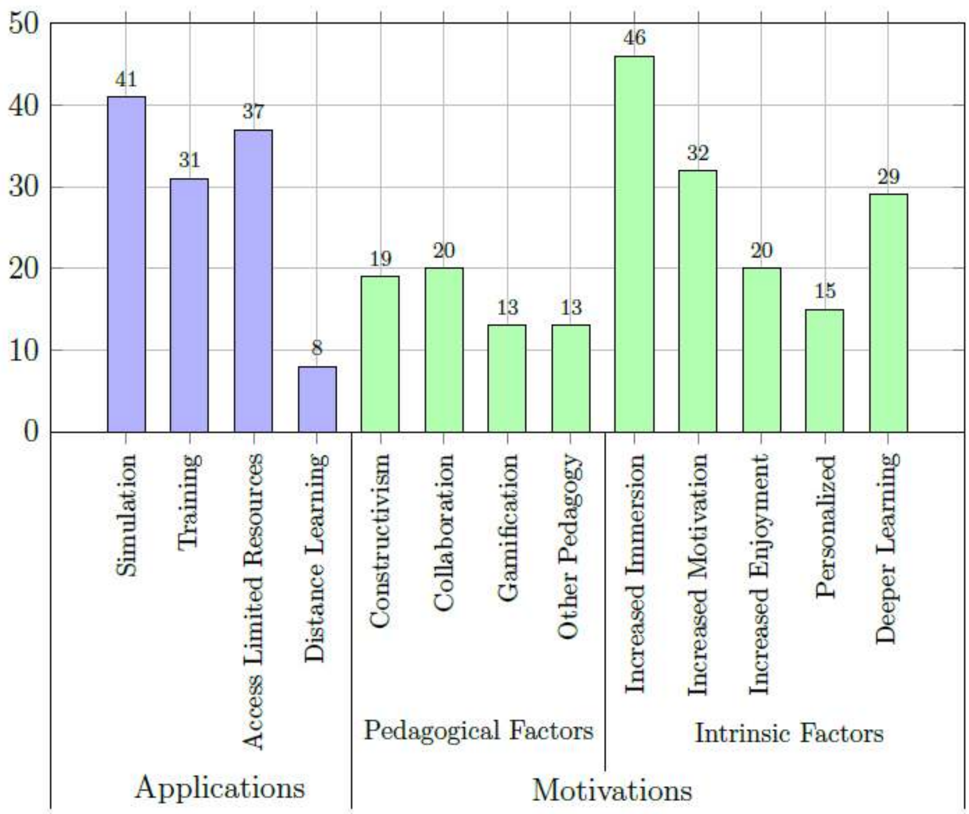


**Figure 5. Reported applications and motivations (obtained via thematic analysis) of 90 papers applying VR to education**

***Simulation***. VR provides the possibility for participating in lifelike simulations/virtual explorations that would otherwise be infeasible or too dangerous to undertake in reality (Abdul Rahim et al., 2012; Sun, Lin, & Wang, 2010; Wei et al., 2013). Public schools providing ancient history courses are unlikely to consider frequent international travel for their students a viable option; however, through VR these same students could explore the architectural brilliance of the Pantheon or even purely imaginary structures without ever leaving their classroom. Gaitatzes et al. (2011) demonstrate an example of VRs ability to simulate activities that while possible, are infeasible; their system was developed in order to simulate and allow the virtual exploration of locations of Greek cultural heritage. Using a joystick-like interaction device, users can freely explore virtual areas and buildings; even examining and interacting with their contents. While visiting the sites contained within the simulation *is* technically possible, it is likely infeasible for classrooms on a budget and/or located elsewhere in the world.

Demonstrating a simulation which *would* otherwise be impossible, Perez-Valle & Sagasti (2012) developed a virtual system allowing students to virtually 16th century Spain. Users of the system are able to explore (in much the same way as the above example) locations that no longer exist, including ancient temples as they were hundreds of years ago.

As well as being able to simulate explorations in virtual environments, it is possible to simulate infeasible interactions (Perez-Valle & Sagasti, 2012; Sharma & Otunba, 2012). Sharma and Otunba (2012) for example developed a system for flight attendants to simulate aircraft fire drills. They state that while it is impossible to create fire drills whereby actual hazards are present (and thus passengers react realistically) due to the potential for injury, such a simulation is possible using VR.

***Training.*** Papers were classified as providing training in our analysis if they were intended to facilitate the transfer of practical skills. For example, an application designed to allow students to virtually explore the universe would not be classified as training (as its immediate practical value is limited), while a flight simulator designed for pilots would be. Ambiguities can potentially arise from this definition, but as a guideline papers were classified as training if they were concerned with the transfer of *skills*, rather than purely knowledge. A close interrelationship also exists between training and simulation applications (as discussed in the section above), however it is not a one-to-one relationship; the 16th century virtual recreation of Spain created by Perez-Valle & Sagasti discussed above for example is clearly a simulation, however it is not used for any training purposes.

The use of VR to facilitate training however is a common form of simulation (58% of simulations identified were designed for training purposes). The training activities simulated in the papers analyzed are diverse, ranging from flight simulations (Wei et al., 2013), to chemical engineering (Abdul Rahim et al., 2012), and construction (Zita Sampaio & Viana, 2013).

Particularly common is the use of VR to simulate medical activities. Though this generally involved the application of VR to surgical activities (Falah et al., 2014; Ferracani et al., 2014; Gutierrez-Maldonado & Ferrer-Garcia, 2013; von Zadow, Buron, Sostmann, & Dachselt, 2013), it can also be used to simulate other medical activities such as rehabilitation. Nolin et al. (2016) for example created a virtual classroom to facilitate the rehabilitation of children with attention deficit disorders, while work by Chang et al. (2014) investigated the potential VR holds to motivate patients suffering from Cerebral Palsy.

The ability to simulate these and other dangerous activities is a common application of VR. Another common example of this is the use of VR to facilitate pilot training. Flight simulations allow virtual flights to be carried out in much the same way as the highly computerized piloting that is done today, and was one of the earliest applications of VR (Page, 2000). Such simulations can be done without the danger to both trainee pilots, and others involved training process (Page, 2000; Wei et al., 2013). Similarly in surgical education, '*In a computer-generated virtual model, there is no patient who might suffer*' (Haluck, 2000).

***Access limited resources.*** While VR can be used to simulate infeasible activities, it can also be used to simulate the access of limited resources. This was a characteristic of 37 of the papers analyzed. The term 'resource' in this case is used to describe any thing which is in high demand and/or limited supply. In VR, where the objects we can include are relatively limitless; these limited resources can include not just resources in the traditional sense, but scientific equipment and even the labs containing them. Examples of the simulation of such labs and equipment are provided below.

Rahim et al. (2012) simulated a commercial milk powder processing plant. The authors designed this system for students of chemical and process engineering, stating that such plants were becoming increasingly difficult to visit due to availability and safety regulations.

A virtual wind farm to facilitate wind energy education was designed by Abichandani et al. (2014), Users could modify the parameters of the wind farms and the wind turbines they contained, these modifications would result in immediate changes to both the appearance of the environment and the underlying data/visualizations produced. As Ewert et al. (2013) point out, such systems allow students to experience settings that would otherwise potentially require excursions or internships.

Hristov et al. (2013) took a different approach, instead allowing students to directly interact with real (physical) laboratory equipment through the use of a virtual environment. While not increasing the supply of resources available; this allows them to potentially be accessed for longer periods of time, and from remote locations.

VR can also be used to simulate the access of non-scientific resources. Angeloni et al. (2012) for example 'brought together' rare and geographically separated pieces of art in a virtual museum for students to explore.

Finally, as mentioned above a popular application of VR is in surgical education. As well as being able to simulate interactions with living patients, in work by both Liu et al. (2014) and Falah et al. (2014) the potential VR has to overcome the limited number of cadavers available to students was discussed.

***Distance Learning.*** Though only mentioned in 8 of the papers analyzed, VR (as with most digital solutions) has the potential to be used for distance learning (Hristov et al., 2013; Pena-Rios et al., 2012). As many of the implementations analyzed were designed to simulate real world learning experiences, the user's physical location is largely irrelevant. Distance learning can allow students to access the learning materials and resources of leading universities worldwide, and some studies have found that students consider it preferable (Hristov et al., 2013; Kiss, 2012; Pena-Rios et al., 2012).

As mentioned above for example, in work by Hristov et al. (2013) students were able to operate real tools located on university grounds through a virtual environment. VR itself is simply a medium to provide distance learning, and can thus facilitate any of its numerous advantages. Students using distance learning desire comparable learning experiences to those provided otherwise. Thus, several of the papers analyzed attempted to provide a distance learning experience using virtual reality that would more realistically map what would be provided in person (Chang et al., 2014; Kiss, 2012; Schwaab et al., 2011).

Chang et al. (2014) for example designed a system to teach users with cerebral palsy how to independently perform rehabilitation exercises. Video tutorials serving the same purpose were previously available; however, there was no way to ensure a person was performing the exercises correctly. To this end the authors developed a VR system using the Kinect motion-sensing device. The system provides real-time feedback to users regarding the validity of their exercise-form based on the angles of their joints, as detected by the Kinect.

Schwaab et al. (2011) were interested in simulating the mock oral emergency medicine examinations provided to students. The authors designed a virtual examination room accessible over the Internet (through the software Second Life) whereby students would assume the role of the doctor, and the examiner would control the patient avatar. 70.3% of the 27 medical students participating in this experiment deemed it to be a more realistic setting than the traditional examination.

### *Motivations*

This section outlines the motivations provided by the authors of the educational VR implementations described in the literature analyzed. These motivations are categorized into two primary themes; *Pedagogical* or *Intrinsic* motivations. These are explained in further detail in the subsections that follow.

***Pedagogical Motivations***. Existing research has shown that VR solutions are effective at multiple level of education, and that students tend to look favorably on them (Auld & Pantelidis, 1994; Huang et al., 2010; Kiss, 2012). VR implementations frequently require some form of input/interaction from the user. Interaction with educational VR systems encourages active engagement; this is preferable to learning through simple *passivities* (Panteldis, 2009). The use of VR in education is at the core of what has been termed Virtual Reality Learning Environments or VRLEs (Huang et al., 2010). A VRLE is one that simply provides an immersive 3D environment that students are capable of interacting with. Though existing studies have demonstrated positive student perception of VR in education, Huang et al. (2010) point out that '...all worthwhile educational innovation must begin with a strong pedagogy'. The distribution of pedagogical motivation factors identified in our analysis is displayed **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**.

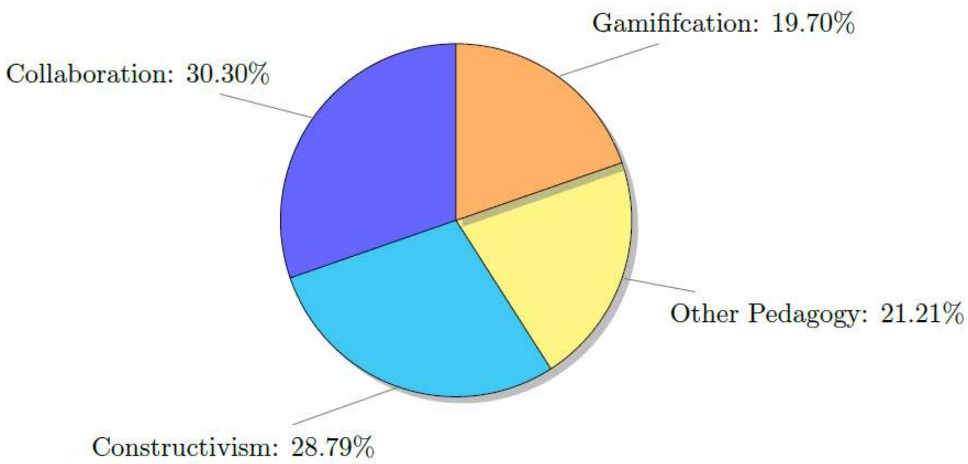


**Figure 6. Distribution of the pedagogical motivation factors identified in our first thematic analysis**

***Constructivism.*** Constructivism is a learning paradigm that argues that humans generate meaning through an active, constructive process. It further posits that learners actively and continually create their own subjective representation of reality based on the interaction between their ideas and experiences (Dewey, 1985; Huang et al., 2010).

The use of VR in education has obvious ties to constructivism (Anopas & Wongsawat, 2014; Huang et al., 2010; Panteldis, 2009). John Dewey believed that the environment has a strong effect on the learner, and that education should be experimental and experiential (Dewey, 1985; Huang et al., 2010). These are qualities that can obviously be facilitated through the use of VR in education.

***Collaboration.*** The collaborative potential of VR solutions similarly aligns closely with *social* constructivism as well as several other of Vygotsky's ideas (Huang et al., 2010). For example, the ability for students to explore these virtual environments either alone or with the aid of other students or teachers lends itself well to Vygotsky's Zone of Proximal Development or ZPD (Huang et al., 2010). The collaborative potential for VR solutions is a common motivator among the papers analyzed, being mentioned in 20 of texts, and accounting for 30.3% of the total pedagogical motivations provided. Several of the papers analyzed in this review employed collaborative aspects to their implementations.

The aircraft fire drill software described above for example was designed to be multi-user, allowing multiple flight attendants to attempt to control and direct the passengers simultaneously (Sharma & Otunba, 2012).

Several implementations were actually designed with communication and collaboration as their *primary goal*; work by Aylett et al. (2014) for example investigated the potential VR held to break down barriers, reduce prejudice and improve communication between children.

***Gamification and Game-based Learning.*** Gamification is the application of game-mechanics, and/or other game-like elements to non-gaming situations, usually (in the case of education) to increase student motivation, engagement and enjoyment of the learning experience. Despite VR often being associated with games, only 13 papers used game-based learning or gamification in their implementations.

Afonseca et al. (2013) developed a marine life game designed for children with down syndrome. Students could watch virtual marine life move about in its 'natural' habitat. Students were also asked to participate in simple identification exercises and quizzes, such as ranking animals in the food chain. The software was designed to appear informal, fun and inviting to users.

The virtual art museum mentioned above and designed by Angeloni et al. (2012) also incorporated game-aspects. As well as simply being able to explore the virtual environment undirected, the system contained several 'mini-games' such as crosswords and treasure hunts. These mini-games encourage users to further explore the museum, and to do so in a directed, goal-oriented fashion.

Aylett et al. (2014) took a different approach, instead creating a virtual implementation of *Werewolves*, a game traditionally played in person. This allowed the authors to design a system such that several students are able to work together to attempt to beat several non-player characters (NPCs). The system both encouraged collaboration and reduced the number of students required to play the game.

Perez-Valle et al. (2012) created a detailed VR game designed to facilitate education regarding 16th century Vitoria-Gasteiz in Spain. The authors have attempted to design a system closely resembling modern role-playing games (RPGs). In it, players must fight their way through the city, working their way through levels of increasing difficulty designed to keep students engaged. The game is designed to route students through notable locations, whereby they frequently encounter NPCs who provide further information regarding the city.

***Other Pedagogical Approaches***. Several papers referenced previous work they had done in the area which they found effective, and had thus replicated their approaches in the study analyzed. Little mention was given to pedagogies *not* rooted in constructivism. As mentioned above; even when pedagogical beliefs were not directly attributed to constructivism, one could argue they were very closely aligned; Rupasinghe et al. (2011) for example were motivated by 'the importance of play' as an intellectual activity, as well as the ability VR systems have to allow students to 'explore' the educational environment.

Chandramouli et al (2014) alternatively emphasized the importance of Active, Project, and Scenario-based learning for providing education into practical 'real-world' skills. The authors believed that VRs ability to simulate practical hands-on education could help facilitate these learning approaches.

Angeloni et al. (2012) cited work by Prensky regarding 'digital natives' (i.e. modern generations frequently exposed to new digital technologies). The authors believed that educational software needs to be designed with consideration to these users. While potentially exciting to older generations, the authors argue that more effort is required to ensure educational software remains appealing to digital natives (who are less likely to be won over by the novelty of educational technologies).

***Intrinsic Factors.*** A desirable characteristic of VR in education is its potential to immerse, or engage users. Unlike motivation (which is discussed more in the section below) which refers to ones desire to undertake a task, immersion refers to ones tendency to *stay* on it (Cecil, Ramanathan & Mwavita, 2013). The increased immersion facilitated by VR was mentioned as a motivational factor in 46 of the papers analyzed (making it the most commonly mentioned factor).

Immersion in a digital environment while not important on its own, can lend itself to many other motivations and applications; time-on-task, exploratory learning, simulation, constructivism, and deeper learning for example.

In their discussion of immersion, Ewert et al. (2013) provide an analogous example of the desired effect: 'In gaming circles, the term [immersion] is used by gamers in order to explain to what extent a game can draw them in and allows them to "lose" themselves in the world of the game'.

Jacobson et al. (2005) describe this effect slightly differently. Instead of stating that immersion causes users 'lose' themselves, they state that the sense of immersion provided by VR provides a sense of presence, and that 'this can be used to focus a students' attention on the subject matter'.

In the description of their aircraft evacuation training software, Sharma et al. (2012) stated that the sense of 'being there' facilitated by VR allowed them to more realistically conduct experiments into how people would behave in such a situation.

Pena-Rios et al. (2012) stated that one of the motivations for designing their mixed reality laboratory to be operated within a VR environment was to 'increase the sense of presence felt by users'.

HMDs can potentially further increase the immersion facilitated VR, literally immersing users; enveloping their vision and lessoning the possibility for visual distractions (Rizzo et al., 2000).

***Increased Motivation***. As mentioned above, we define motivation in our analysis as the desire, or incentive held by a student to participate in a learning activity. Our thematic analysis revealed that this was the second most frequently mentioned motivational factor, occurring in 32 of the papers. VR possesses several characteristics that can make it appealing to educators wishing to improve student motivation.

The simple novelty of interactive technologies themselves, including VR is mentioned several times as a factor which can improve student motivation (Ewert et al., 2013; Huang et al., 2010; Zavalani & Spahiu, 2012).

These technologies make it possible to develop interesting software and activities that can better motivate students than traditional methods (Gieser, Becker & Makedon, 2013).

Huang et al. (2010) cite several sources of existing research into motivation and VR, amongst which state that:

- Better motivated students have a tendency to learn better (Sutcliffe, 2003).
- Students are typically more motivated by 3D graphical applications than 2D (Limniou, Roberts & Papadopoulos, 2008).
- The continual use of interactive VR can both improve student motivation and retention (Burdea & Coiffet, 2003).

As mentioned above, patients suffering from cerebral palsy are often prescribed sets of rehabilitation exercises. Chang et al. (2014) however state that patients frequently fail to bother completing them. In an attempt to utilize the motivation facilitated by VR, the authors developed a Kinect-based system capable of guiding patients through the rehabilitation exercises.

Gamification, as mentioned above (and discussed in *Increased Enjoyment* below) is also a potential means of increasing motivation. Sharma et al. (2012) in their aircraft evacuation system designed it to include gamification aspects to increase motivation; the system contained a series of game-like objectives as well as a point-based scoring system.

***Increased Enjoyment***. Closely related to *Increased Motivation*, a many papers (20) were motivated by the belief that simply using VR would increase student enjoyment.

Of the 20 papers that reported this as a motivational factor, 13 employed either gamification or game-based learning. Thus, all 13 papers that utilized gamification or game-based learning reported increased enjoyment as a motivational factor.

The remaining 7 papers described either novelty, or the increased interactivity typically provided by educational VR systems as explanation for why their system would result in increased student enjoyment (Fabola & Miller, 2016; Piovesan, Passerino & Pereira, 2012; Tsaramirsis et al., 2016).

***Personalized Learning.*** A motivation commonly cited by authors in the literature was the potential VR holds to facilitate personalized learning experiences, i.e. lessons tailored to the needs of individual students. This was mentioned in 15 of the papers.

Educational virtual reality software potentially allows students to explore and learn at their own pace. This is appealing to both students and educators attempting to teach students of different abilities (Angeloni et al., 2012; Chang et al., 2014; Chung, 2012; Gieser et al., 2013; Perez-Valle & Sagasti, 2012) .

Afonseca et al. (2013) for example was concerned with the development of educational software for children with Down syndrome. The authors expressed their desire to provide learning experiences that would scale according to the unique abilities of the students.

Another potential means for providing a self-paced learning experience; using VR students can potentially repeat lessons (without the need for an instructor) as many times as they want (Tredinnick et al., 2014).

Besides learning-related abilities, VR also provides potential to create lessons that change according to other needs held by the student. For example, as mentioned above Chang et al. (2014) created a system to motivate and educate patients suffering from cerebral palsy as to how to go about performing rehabilitation exercises. The lessons provided by this software would change according to the personal requirements (in terms of exercises required) of the user.

While many of the papers identified during this systematic review were motivated by this factor, the idea of using VR to facilitate personalized learning is not a new one; in 1998 for example Johnson et al. discussed the relationship between personalized learning and constructivism. They pointed out that constructivist ideals revolve around the idea of self-directed learning, and that this is something one could facilitate through the creation of personalized virtual learning environments (Johnson et al., 1998).

***Deeper Learning.*** Similar to the pedagogical motivations mentioned above (especially regarding constructivism), VR solutions were commonly motivated by the authors' belief that they would facilitate *deeper* learning experiences than what is provided by traditional teaching methods. This was mentioned in 29 of the papers analyzed.

While few of the papers motivated by this factor explicitly mentioned constructivism, many appeared to have their beliefs rooted in constructivist ideals. The message frequently portrayed by authors is that VR will stimulate deeper learning as students are able to explore, immerse, and infer their own meaning from their experiences within the virtual reality (Chung, 2012; Falah et al., 2014).

It is also stated that the experiential learning process facilitated by VR is more realistic and potentially valuable to students embarking in practical fields than traditional teaching methods (Chandramouli et al., 2014; Falah et al., 2014). Moreover, as Zavalani et al. (2012) state; students learn best when they are exposed to a variety of teaching techniques and learning experiences.

In the design of their medical training system for anatomy education for example, Falah et al. (2014) state that they created it because unlike traditional content delivery; using VR transfers the learning experience from being one that involves simple memorization to one that promotes deeper understanding.

### *Problems with Virtual Reality in Education*

Given the fact that VR has not been adopted despite the aforementioned motivations, advantages, and long history; it is safe to assume there also exists substantial issues and limitations.

The following section is structured similar to the section *The Applications and Motivations of VR in Education* above. We begin by first performing an analysis of the reported issues and limitations identified in literature utilizing VR in education. We then identify the primary issues and patterns in the data analyzed, before discussing and elaborating on them in the subsections that follow.

### *Thematic analysis results*

Our second thematic analysis into the problems with VR in education identified 11 common characteristics/codes in the papers analysed, which in turn could be categorized into 4 main themes; *Overhead, Input Problems, Output Problems* and *Usefulness* (see **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**7).

Overhead refers to issues associated with the costs (both monetary and otherwise) associated with designing, or employing VR software in education. This encompasses the codes *Training* and *Cost*, which account for 6 (8.2%) and 9 (12.3%) of the 73 (not including *No Reported Issues*) total issues recorded respectively.

Input Problems refer to all issues involving providing input to the VR system. This encompasses the codes *Input Hardware Usability, Recognition Inaccuracies*, and *Lack of Feedback*. Recognition Inaccuracies was the most frequently mentioned issue in this category, accounting for 7 (9.5%) of the total issues reported.

Output problems similarly refer to all issues involving the output provided by the VR system. This encompasses the codes *Insufficient Realism, Software Usability* and *Motion Sickness*. Software usability was by far the most frequently mentioned issue both in this category, and in the whole analysis; accounting for 17 (23.3%) of the total issues reported.

Our final theme Usefulness refers to the effectiveness of the system in its educational context, i.e. whether it is fit for purpose. This encompasses the codes *Ineffective* and *Lack of Engagement*, which account for 6 (8.2%) and 11 (15.1%) of the total issues respectively. Thus, a lack of engagement was the second most commonly reported issue identified in our analysis (after software usability). Though not an issue in itself, papers that expressed *No Reported Issues* were also displayed here in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**7.**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**

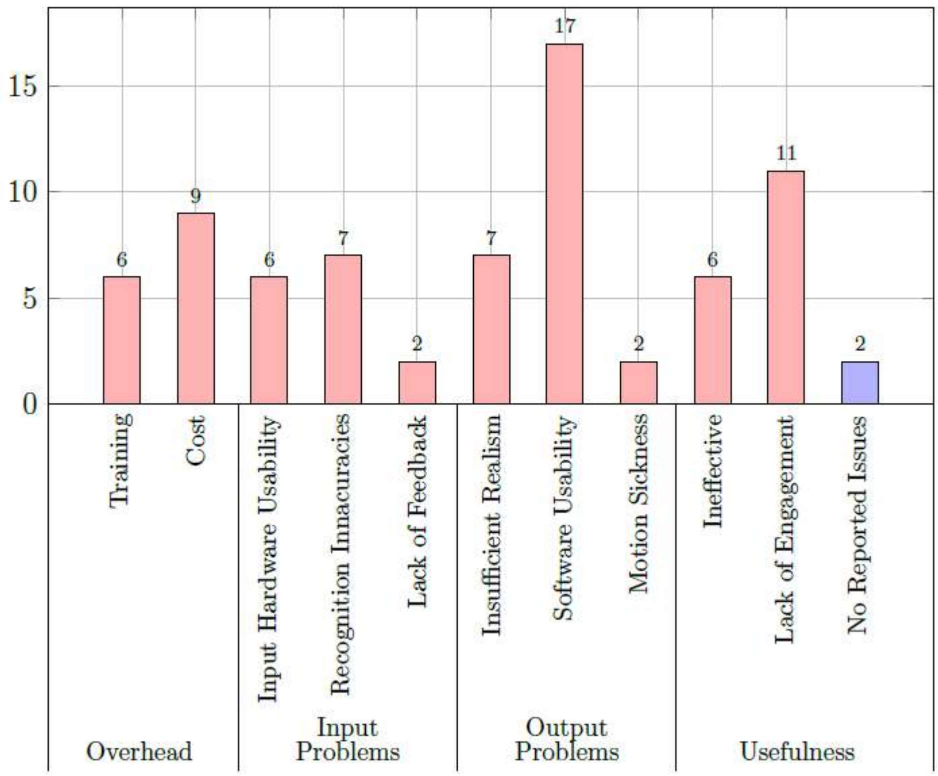


**Figure 7. The Issues and Limitations of Virtual Reality in Education. Reported issues and limitations (obtained via thematic analysis) of 35 papers applying VR to education**

Though we have attempted to minimize overlap between these categories, it is still possible; this is particularly difficult to avoid between the themes of input and output problems. A typical VR HMD for example is both simultaneously an input and output device.

The remainder of this section explains and elaborates on the issues identified above, providing examples from the relevant literature where necessary.

***Overhead.*** Utilizing VR solutions in the classroom can incur substantial overhead, in terms of both the setup time, the software and hardware costs, as well as training of both students and educators. These factors were mentioned in 10 (28.6%) of the 35 papers we looked at in this analysis.

***Cost.*** A commonly cited reason for the lack of adoption of VR in education is the cost associated with doing so (Budziszewski, 2013; Huang et al., 2010; Kaufmann & Meyer, 2009; Merchant et al., 2014; Mossel & Kaufmann, 2013; Takala, 2014). Utilizing VR software in the classroom involves not only the costs associated with the initial purchase of hardware and/or software, but ongoing costs including maintenance, support, and training (discussed more in the Section *Training* below). However, the actual cost of the initial purchase of educational VR technologies can also be high, and many schools may be unable to justify the expense.

Given the currently small market for VR educational technologies, on the other side of the table it may be difficult for manufacturers and developers to justify undertaking such projects. This will likely further decrease both the adoption rate of VR technologies in education, and the quality of those that are produced (Deb & Ray, 2016). While it was not included in this analysis (due to not meeting our inclusion date criteria), several papers cited the 2007 educational game *Arden, the world of Shakespeare* which exemplified this issue. The project was cancelled even after receiving a $250,000 USD grant, with the creator stating that one of the reasons for its failure was the *amount* of funding. Users did not enjoy the game, and while $250,000 may sound like substantial investment, the authors stated that it was a 'drop in the bucket' in comparison to the funding that is required to produce the published games users are probably familiar with (Naone, 2007).

While many of these technologies may not be currently affordable for individual or classroom use (especially those utilizing technologies such as CAVE-based environments), such systems can still be utilized in other educational settings, such as a museums (Angeloni et al., 2012; Apostolellis & Bowman, 2014; Hsieh et al., 2010).

Though Wiecha et al. (2010) admit that using technologies such as SecondLife involves costs in terms of requiring students to possess (or at least have access to) computers and the Internet, conversely their students (who potentially already possess the required hardware) reported that they appreciated the fact that they could *save* money on transport through the distance learning the system facilitated.

***Training.*** A similar issue involves the amount of overhead in terms of the training time required of educators. When a new digital technology is employed in schools, there is often the need to organize training sessions for educators (Haluck, 2000; Le, Pedro & Park, 2014). This issue is closely related to the above issue of cost, in that institutions will likely have to pay the teachers and/or instructors for these training sessions. The issue of training-related overhead was mentioned in 6 (17.1%) of papers.

As the costs for educational VR technologies can vary, so too can the amount of training that is required of both staff and students. While educators may be familiar with the use of desktop PCs, it is less likely they are familiar with the workings of CAVE systems or HMDs; this too could require additional training (Wang & Lau, 2013; Wiecha et al., 2010).

A long-standing additional problem in the field of computers and education is the fact that the amount of training required is not predictable; instead educators of differing levels of technical ability will require more or less time to train (Haluck, 2000).

Finally, these issues are also potentially applicable to the students themselves. Teachers may have to spend time training students on how to use the educational systems and their underlying technologies; this in turn could detract from the amount of time available for teaching (Le et al., 2014).

***Input Problems***. VR solutions frequently employ specialized hardware, these can be both more physically demanding, and less accurate than the more popular hardware (Abdul Rahim et al., 2012). However, the requirements of specialized hardware (such as HMDs) and other interaction issues can render them nonetheless desirable.

As usability issues and recognition inaccuracies are closely related problems occurring with a multitude of specialized VR input devices, the corresponding codes of *Input Hardware Usability* and *Recognition Inaccuracies* have been combined below.

***Input hardware usability and recognition issues***. The unique requirements of many VR implementations can call for specialized hardware which users may be unfamiliar with. For example, systems employing a HMD may find a keyboard-and-mouse interaction paradigm unsuitable; as this would potentially require users to possess the ability to touch type. The resultant multitude of specialized input devices that can be applied to VR systems can in turn each potentially possess their own set of unique usability issues, these can vary further based on the requirements of the system and the abilities of the users (Afonseca & Badia, 2013). While for example a new touch screen device may present usability challenges to some (Abdul Rahim et al., 2012), a simple digital pen may be all it takes for others (Afonseca & Badia, 2013).

Input Hardware Usability issues occurred in 6 (17.1%) of the papers analyzed, while recognition inaccuracies that arose in implementations utilizing specialized hardware occurred in 7 (20%) of papers.

Gesture recognition systems are one approach to providing input to VR systems. Being able to perform freehand gestures can potentially be more natural (in that it is closer to how we interact in the 'real world') than the mouse and keyboard (Gieser et al., 2013). Naturalness of interaction is a desirable quality for VR systems attempting to simulate reality (Gieser et al., 2013; Takala, 2014). However, gesture recognition systems are currently imperfect; suffering from a multitude of problems ranging from usability issues such 'gorilla arm syndrome' (Carmody, 2010), to recognition problems including occlusion, gestural ambiguities and simple recognition inaccuracy (Gieser et al., 2013).

Soe et al. (2013) for example designed a system to promote and facilitate STEM education. The authors however found that interactions with their solution (which used the Kinect motion sensing device) were often counter-intuitive, inaccurate, and could have actually detracted from the overall experience.

Even highly accurate gesture recognition systems still suffer from a plethora of limitations. Gietzer et al. (2013) for example wished to employ the advanced VICON marker-based tracking system in their implementation. As well as being highly expensive the authors noted that this required users to wear a full tracking suit for recognition purposes. This was both time-consuming and provided for an unacceptable level of usability.

***Output Problems.*** As with input devices, there exist numerous technologies which can be used to display output to the users. These range from immersive head-mounted displays, to

CAVE environments, to the standard digital screen. These devices have their own advantages and limitations, facilitating differing degrees of realism.

The usability of the software outputted to these devices is also an important factor in any VR implementation, as it represents the ease with one is able to interact with the virtual environment designed.

***Insufficient Realism***. Depending on the context, there may exist a need to provide a virtual experience which closely maps the real (physical) one. 7 (20%) of the papers analyzed reported issues relating to the fact that their system provided an insufficiently realistic experience. This accounted for 26.9% of the total output problems reported.

Several papers reported that the users of the systems found their implementations to be insufficiently realistic, and authors worried that this may detract from the learning experience (Huang et al., 2010; Le et al., 2014).

Certain situations require a more realistic experience than others. Failing to provide a realistic experience in the surgical simulations mentioned above for example could not only provide for a weakened learning experience, but actually negatively impact the students.

Schwaab et al. (2011) for example designed a VR system to simulate mock medical emergency oral examinations. While the majority of the students reported that they preferred the VR system to the traditional approach; several also claimed that it did not realistically reflect their practical experience, and would therefore provide limited benefit to their learning.

As well as limitations to the realism provided by the virtual environments, there can also exist limitations to the devices providing them (low pixel density, image latency etc.; Cuccurullo et al., 2010; Hsiaoa et al., 2010). The potential for newer devices to overcome these limitations is discussed in further detail in the section *Potential New Approaches* below.

***Software usability***. Software usability issues were by far the most commonly identified problem reported, occurring in 17 (48.6%) of the 35 papers analyzed.

The nature of these usability issues varied substantially depending on the nature of the software, and encompassed problems ranging from interface design, to interaction quality, to readability (Hsiaoa et al., 2010; Hsieh et al., 2010).

While some of these issues can be attributed to unfamiliarity with the technologies, others arguably arose simply as a result of issues with the software design (Falah et al., 2014; Rus-Casas et al., 2014; Wang & Lau, 2013). Users of the VR medical training system for anatomy education designed by Falah et al. (2014) for example reported that their usability issues resulted simply from problems understanding and navigating the systems interface.

Similarly, Huang et al. (2010) reported that it was common for students to get lost while exploring badly designed virtual environments. These issues can be avoided through more careful software design. For example, Angeloni et al. (2012) in the design of their virtual art museum included a virtual map and compass accessible to users at all times to avoid this same issue.

***Usefulness.*** The following section outlines issues identified pertaining to the usefulness of the systems described in the papers analyzed. By usefulness, we refer simply to whether the system created was fit for purpose; i.e. whether it provided an effective learning experience. Usefulness-related issues accounted for 17 (23.3%) of the total issues identified in this analysis.

***Lack of engagement.*** Of the 35 papers analyzed, 11 (31.4%) reported a lack of student engagement with the systems they designed. This was most frequently described in the form of 'boredom' expressed by students (Hsiaoa et al., 2010; Hsieh et al., 2010).

Increased user-motivation was identified as a justification provided in 33.7% of papers in our first analysis, it is interesting therefore to note that similarly 31.4% reported this to be an issue in the second. Attempting to pinpoint a single cause for a lack of engagement with the VR solutions is difficult and likely futile; instead its relatively high occurrence probably results from a culmination of the issues identified above.

While the novelty of using VR for education arguably reduces the likelihood for boredom, educators should be careful not to rely on this as their *sole* means of facilitating student engagement, as poor educational design (even within VR) can still result in a lack of engagement (Allison & Hodges, 2000; Apostolellis & Bowman, 2014; Ip, Byrne & Cheng, 2010).

***Ineffective.*** Relatively few (6, 17.1%) papers reported that their implementations were simply ineffective, and of those that did several based this conclusion solely on user evaluations (Le et al., 2014; Rus-Casas et al., 2014). Furthermore, the evaluations of these papers returned results that did not contain unanimously (or indeed primarily) negatively feedback.

The variance in user perceived effectiveness of these systems could however potentially demonstrate that people react to VR educational systems differently. For example, in their recent paper *Werewolves, cheats, and cultural sensitivity* Aylett et al. (2014) developed a system to fight prejudice and promote sociability among students; while the system had positive findings for male participants, girls did not demonstrate any change in behavior as a result of using the software.

### *Other factors*

There were several additional factors (see Table 2) identified during our analysis, however they were not included because they were either overly specific to a particular context or to a particular implementation. Several issues which were mentioned infrequently but could nonetheless reoccur if the analysis was repeated over a larger sample size are discussed below.

Firstly, two papers reported that the lack of tactile feedback provided by their input system had the potential to cause usability issues (Chang et al., 2014; Cheung et al., 2013). While (as discussed above) gesture recognition can provide a very natural form of input to users, the lack of tactile feedback provided by such systems can potentially detract from their immersion, realism and overall user experience.

Strangely, despite being commonly associated with VR (Abdul Rahim et al., 2012; Huang et al., 2010; Merchant et al., 2014; Rizzo et al., 2006); only 2 of the 35 papers analyzed reported issues with motion sickness (Abdul Rahim et al., 2012; Nolin et al., 2016); this is despite the fact that many utilized HMDs.

**Table 2. Other issues and limitations mentioned in 22 papers utilizing Virtual Reality in an educational setting**

| Other factors | | |
|---|---|---|
| Lack of Feedback | Motion Sickness | No Reported Issues |
| 2 | 2 | 2 |

Finally, arguably a problem in itself; only 2 of the papers analyzed reported that the systems functioned as intended *without* any usability issues.

### Potential new approaches

So far we have discussed existing approaches and applications of VR to education. We have also looked at authors' motivations and justifications, as well as separately analyzed the reported limitations and issues with their systems.

We now turn our gaze to the future; in this section a range of new and upcoming technologies are introduced and compared to those used in the aforementioned analyses. By analyzing the technologies respective specifications (where available) we then discuss the potential these technologies have to overcome some of the issues and limitations identified in the sections above.

### Virtual reality resurgence

Recently consumer interest in VR has sparked a wide range of new and often crowdfunded virtual reality devices (Le et al., 2014; Merchant et al., 2014; Wang & Lau, 2013). While for the most part these technologies have already existed for a long time in one form or another, this latest iteration could potentially overcome (or at least lessen) some of the various long-standing issues plaguing them. These issues range from those identified in the analyses above, such as accuracy, usability, and price to non-technological issues like consumer availability.

As mentioned above, these technologies differ from previous iterations in one main regard; instead of being funded through private/scientific investments, many of them are instead crowdfunded as a result of consumer interest in the product (Control-VR, 2014; Cybreth, 2013; Oculus, 2012; Omni, 2014; PrioVR, 2014).

It is likely that this shift in investment model will see VR technologies increasingly target a wider, consumer-based audience. Whether this will in turn constitute decreases in costs and/or increases in product usability (or improvements to any of the aforementioned limitations) is discussed below.

### Virtual reality peripherals matrix

While it is possible devices of importance have not been included in the following discussions, we have attempted to include a large number of the recent (popular) input and output peripherals of interest to VR communities. In order to gain a better understanding of patterns and/or any discrepancies in the specifications of upcoming devices, we have also tabulated them (as well as the devices respective functionalities) into the large 'Virtual Reality Peripherals' matrix included in the papers Appendix; see Figure 10 and Figure 11. It is important to note that data pertaining to the specifications of many of these devices is currently unavailable. This is primarily because the devices are either still lacking a consumer version (correspondingly noted in Figure 10 and 3), or have only recently been released. The metrics contained within the matrix have been taken from the manufacturers specifications where possible, otherwise from peer-reviewed sources who have independently tested the technologies.

### Overcoming Existing Limitations

Despite these limitations in data availability, the following sections will discuss the potential the technologies included in the matrix have to overcome some of the more prevalent limitations and issues currently plaguing VR in education (as identified above).

***Usability and training.*** Once again it is important to reiterate; many of the devices included in this matrix are part of a new iteration of VR technologies funded by, and/or intended for use by end users. Moreover, devices that were not crowd-funded are also often backed by either gaming companies (as is the case for the Nintendo Wii, Razer Hydra) or by popular producers of consumer electronics and software (Microsoft Kinect, Sony PlayStation VR and Facebook's Oculus Rift).

What this potentially means is that unlike VR peripherals of the past, which were often designed in an academic setting solely for research purposes (whereby comfort and usability were rendered secondary factors); these businesses likely consider the usability of their devices (and thus enjoyment of their stakeholders) of great importance (Naone, 2007).

A system which is designed with consumer usability in mind will also likely be easier to train users (and in this case students) in. Future work is however needed to evaluate whether any potential decrease in training time is sufficient to spur their adoption in education.

***Recognition inaccuracies***. Of the usability issues identified in the papers, one of the more common was that of input hardware recognition inaccuracies. The Microsoft Kinect was the only gesture recognition platform commonly utilized in the papers analyzed. However, there now exists a multitude of gestural recognition systems capable of higher degrees of recognition accuracy, whilst remaining relatively affordable.

Though these technologies have the *potential* to allow up to sub-millimeter recognition (as is the case for the Leap Motion, see Figure 1113 for a detailed comparison), occlusion, false-recognition, gestural ambiguities and a multitude of other long-standing issues still have the potential to negatively impact the usability of many of these systems.

Until these problems are resolved, this latest iteration in devices may do little to improve this issue.

***Realism.*** Several of the papers analyzed reported that students found the VR environments to be insufficiently realistic. Authors worried that this lack of realism may remove from the immersion desired from a virtual reality, and in turn detracted from the overall learning experience (Hsieh et al., 2010).

Devices such as the Oculus Rift act as an alternative output peripheral to the traditional screen, and as such bring nothing new to the realism (in terms of graphical appearance) of environments. By acting as a simple output medium however (and not performing the graphics rendering onboard the device), devices like the Oculus Rift will however continue to be able to facilitate improved realism (as it happens) through the continuing advancements made in the field of computer graphics.

The Oculus Rift *does* however contain several additional characteristics which have the potential to provide improved realism (the most obvious of which is complete visual immersion in the graphical environment). Though the current consumer version ships with a resolution of 1080 x 1200 per eye, later versions will likely ship with higher resolutions (Paterson, 2015). Without a sufficiently detailed display, improvements in computer graphics would be otherwise be rendered relatively pointless.

Finally, the developers of the Oculus Rift have managed a design facilitating low levels of latency (around 20ms; see Figure 11 13). This low latency improves the fluidity and naturalness of interaction, simultaneously decreasing the risk of motion sickness and improving the perceived realism.

Continual improvements in the usability and recognition accuracy of input peripherals additionally have potential to improve the realism of the user's interaction experience within such a display.

***Cost.*** Finally, we now discuss the potential that the upcoming wave of VR devices have to overcome the issues of pricing and other related costs that are traditionally involved in employing VR systems in education.

It is impossible to state whether any of the devices included in the peripherals matrix are unequivocally 'affordable' or not, given the huge variance in the means and funding that exists between different schools. Therefore, we instead focus our attention on general trends and anomalies in the pricing patterns (as per Figure 11 13) of the devices.

What is immediately obvious is that there now exists large differences in the pricing of relatively similar devices. Furthermore, discrepancies exist in the prices of these devices in terms of the respective accuracy they provide; in other words, many low-end devices purport specifications higher than those of their pricier alternatives.

Several of the more advanced gesture recognition systems come in tiered-pricing plans. While the basic system may appear comparatively affordable, their prices however quickly grow. For example, the STEM VR systems starts at $220 USD, however if one wants to improve recognition (through the purchase of further sensors) the price of the device quickly rises up to $580.

There does exist several VR input peripherals around the $100 USD price mark, namely the Leap Motion and PlayStation Move controllers. It is important to note however that neither of these devices are complete systems; but instead require the purchase of potentially (and indeed likely) more expensive base-hardware.

Nonetheless, compared to other consumer electronics utilized in educational settings (a projector for example) even pricier devices like the Oculus Rift appear relatively cheap in comparison.

While we cannot definitively state that these devices will be suitably priced for widespread educational adoption; one can hypothesize (similar to our hypothesis regarding usability above) that they will be increasingly developed with affordability in mind.

### *Approaches to interacting with head-mounted displays*

Arguably the device which pre-empted the recent resurgence in consumer interest in VR, the head-mounted display (HMD) is of prime importance to any discussion into the current state and direction of VR (Avila & Bailey, 2014). Despite the upcoming range of HMDs however; there still lacks a fit-for-all, or even widely used output peripheral for interaction with them.

While the mouse and keyboard work fine for desktop interaction, providing input while using HMDs poses a range of additional interaction difficulties (the primary of which is that one is unable to see the device they are interacting with). This problem is potentially compounded in an educational environment whereby one may desire additional interaction functionality, such as the ability to take notes.

However, the continual development of novel input interaction technologies gives potential for new approaches to interacting within such an interaction paradigm. We now provide a few short examples, demonstrating how both these new and old technologies could hypothetically be leveraged and combined to overcome these issues and provide for novel and inventive educational learning paradigms.

***Handwritten Notes.*** Information from external peripherals can potentially be displayed within virtual environments in real time. Theoretically one could put on a HMD, sit in a virtual classroom and take handwritten notes on any number of devices capable of digitally transcribing handwritten notes. The information could then be displayed to students within the virtual environment in a virtual notebook. The actual devices used to provide input could range from a tablet PC, to specialized graphics tablets, to devices that transcribe physical ink-on-paper (such as the LiveScribe digital pen).

Users could however still encounter issues in orienting themselves with the device, i.e. perceiving the physical borders of the input peripheral device solely by touch. Furthermore, if there was to exist noticeable delay between the physical action and the notes being displayed within the virtual environment (the LiveScribe refreshes it's information only roughly once per second for example) then this would result in unnatural interaction paradigm and potentially detract from the learning experience (Huang et al., 2010; Le et al., 2014).

***Capacitive keyboard.*** Similar to the above approach, one could overlay a virtual keyboard within the virtual environment. Though users would still have to reach out and find their keyboards, using a capacitive keyboard could solve the issue of blind-typing for users who are unable to touch type.

Users could simply place their hands on a capacitive keyboard; the keys which are currently being touched (though not fully pressed) could be sensed by the capacitor pads, and then highlighted on the virtual keyboard - allowing users to physically orient themselves through the virtual environment.

***360° video lectures.*** Rather than applying computer graphics to VR in education, one could utilize the capabilities of HMDs to immerse students in digital recordings of real life events. Through the use of camera rigs and other tools capable of capturing 360° video and bidirectional sound, one could record educational environments ranging from significant archaeological sites, to classrooms, lecture theatres and even one-on-one tutorials. Whether 360° video constitutes a true virtual environment is debatable. Exact definitions of what constitutes a *virtual reality* differ in existing literature, though most definitions (minimally) describe a digital representation of a three dimensional object and/or environment. By this definition 360° video (especially when viewed on a VR headset) arguably constitutes a virtual reality.

While the usefulness of such an environment as a teaching tool would need to be evaluated, if effective it could form the basis for the next generation of a huge range of educational systems; such as fully immersive lecture recordings or realistic one-on-one intelligent tutoring systems.

## Discussion

In this paper we have analyzed both the applications and reported motivations for using VR technologies in education, as well as the issues and limitations associated with doing so. Furthermore, we have introduced, compared and discussed a range of recent and upcoming VR related technologies; evaluating their potential to overcome the issues identified in our earlier thematic analyses.

Our initial analysis into the applications and motivations of VR in education provided by authors in current scientific literature yielded some surprising findings.

The applications of VRs usage in education is currently largely skewed towards those for simulations and training purposes. Thus, more work is required to evaluate whether the improved immersion facilitated by tools such as head-mounted displays render them justifiable as an alternative medium for widespread generalizable (i.e. *non*-specialized) applications to digital education.

Particularly prevalent is the use of simulations in the fields of health and medicine, accounting for 35 of the 95 papers analyzed. The institutions for which the educational applications were intended were also largely skewed, with 51% of implementations created for use in higher education.

We also found that despite the fact that much of the literature analyzed was created to inform educational design, little of the research was grounded in solid pedagogical reasoning. Discussing such factors would be beneficial to the designers of future systems.

Increased immersion and user-motivation were the most commonly reported motivations identified in our initial analysis for using VR in education, occurring in 46 and 32 of the papers respectively. However, the most commonly provided justification for increased user-motivation was that authors believed simply utilizing these technologies in education would be enough to motivate students. Though this may be true in the short term, it is important that authors do not become reliant on this factor for motivation, as simple technological novelty will likely diminish with continual use.

Another fairly common application of VR to education was in its ability to facilitate distance learning. Though none of the papers identified in our analysis suffered from this issue; when designing VR educational systems, it is important to remember that designing them around the use of any form of specialized hardware will likely detract from its suitability as a distance learning tool. Designing a VR system intended for use with an HMD for example would require *all* participants of the course to also acquire an HMD. Even if the upcoming iteration of VR HMDs are relatively popular among consumers, such an approach would still likely end up excluding students.

The number of papers that clearly evaluated their systems (including consideration to usability factors) was relatively small, leading to a comparatively smaller second analysis being performed in the Section ***Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.***.

The issues of cost and training contributed to many of the problems identified in our analysis. Over 28.6% of papers analyzed reported issues with the overhead incurred as a result of using VR technologies in education.

By far the most frequently reported issue identified in our analysis was that of software usability. Users reported a multitude of issues, including counter-intuitive interfaces, confusing objectives, and that they would even get lost in the virtual environments (Hsieh et al., 2010; Huang et al., 2010; Le et al., 2014). Further analysis revealed that several of the reported usability issues were simply a result of avoidable software design decisions. As well as software usability issues, several papers reported usability issues arising as a result of recognition inaccuracies and other limitations with the input *hardware*. In the Section *Potential New Approaches* we introduced a range of recent and upcoming VR related peripherals. The specifications for these devices displayed in the virtual reality peripherals matrix (Figure 10 & Figure 11) exhibits their potential to lessen the probability of recognition inaccuracies. However, despite their improved specifications they are nonetheless still plagued by a multitude of long-standing interaction limitations (occlusion, gestural ambiguity etc.).

Although commonly associated with VR (especially head-mounted displays), only 2 papers reported issues with user motion sickness (Abdul Rahim et al., 2012; Huang et al., 2010; Merchant et al., 2014; Rizzo & Bowerly, 2006). Whether this is a result of well-designed implementations, the sample size, or the design of the user evaluations is unknown.

Students in the papers analyzed also frequently reported issues with the lack of realism provided by the educational VR implementations, and authors in turn felt that this could potentially detract from the learning experience (Huang et al., 2010; Le et al., 2014). In the Section *Approaches to Interacting with Head-mounted Displays* we discussed the advent of the resurgent head-mounted display (HMD); we hypothesize that its lower latency, higher resolution and ability to facilitate the continually evolving computer graphics field has the potential to lessen this issue. However, educators with limited time and resources to spend on creating these implementations will likely still have problems creating virtual environments which students find to be sufficiently realistic. To this end educators could potentially consider design factors such as the Uncanny Valley hypothesis, and focus less on creating perfectly realistic experiences and more on those that are simply enjoyable and effective. Alternatively, rather than relying on computer graphics to provide realism, educators could use these developing technologies in combination, such as the HMD with spherical immersive video.

Finally, we also discussed the potential these new technologies have to overcome the issues of usability, cost, and training overhead that have traditionally hindered VRs adoption. It is however, difficult to draw conclusions on any of these issues yet; both metrics and price data is still widely unavailable for many of these devices, and because the definition of what is 'affordable' to schools differs greatly. Nonetheless, we hypothesize that given the crowd-funded investment model and target (consumer) audience of many of these technologies; one can fairly safely assume that usability and affordability will be of prime consideration.

## Conclusion and future work

In this paper we have performed a systematic review as well as thematic analyses into both the applications and author's motivations for using VR in education, as well as the reported issues and limitations associated with doing so.

Our initial analysis demonstrated tendencies amongst educators to frequently apply VR solutions only in specialized situations requiring realistic simulations or for training purposes. Future work is needed to investigate the suitability of VR technologies (such as HMDs) purely as an alternative *medium* for non-specialized digital education. We also discovered that little of the work analyzed was actually grounded in solid pedagogical reasoning. Moreover, much of the research was motivated by intrinsic factors, including the belief that students would be motivated by the novelty of VR technologies; a factor which would likely diminish with continual use.

Our analysis into the reported issues and limitations of VR systems also yielded interesting results, with problems pertaining to cost, training and software and hardware usability accounting for much of the data. Particularly prevalent was the occurrence of software usability issues; occurring nearly twice as frequently as most of the other issue reported. Several authors also reported that students found the implementations to be insufficiently realistic, and claimed that this was a result of the limited time and resources available to them. Future research should therefore investigate the application of design hypotheses such as the Uncanny Valley, or utilize alternatives to computer graphics to provide increased realism, such as spherical immersive (360°) video.

In the Section *Potential New Approaches* we introduced a multitude of recent and developing VR technologies that have arguably been brought about by a resurgence in consumer interest in VR. The potential these technologies have to overcome some of the limitations identified our second thematic analysis was discussed with the assistance of the data contained in our 'Virtual Reality Peripherals Matrix' (Figure 10 & Figure 11). Unfortunately, future work (and time) is needed to provide a complete matrix, as metrics for many of the devices analyzed are still unavailable.

This latest iteration in VR technologies possess their own unique set of interaction requirements and difficulties, especially if one wishes to apply them to an educational context. Thus, we have concluded our paper by providing novel techniques to overcome them, as well as potential directions for future researchers wishing to apply them to education.

## Appendix. Figures representing the results of the thematic analysis in detail

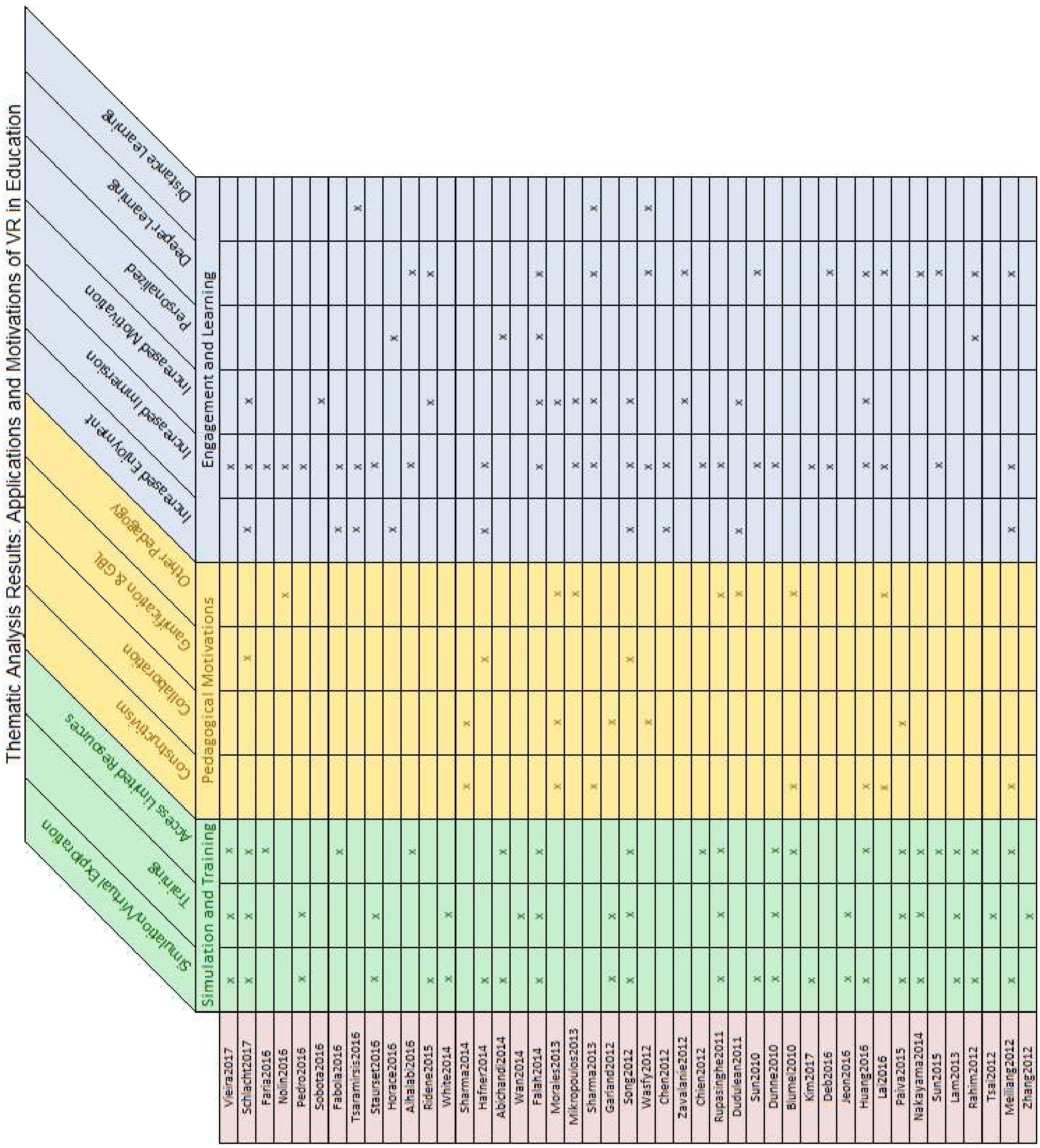


**Figure 8a. Applications and motivations of VR in education, papers 1-45**
**(Full results of the thematic analysis performed on 90 papers**

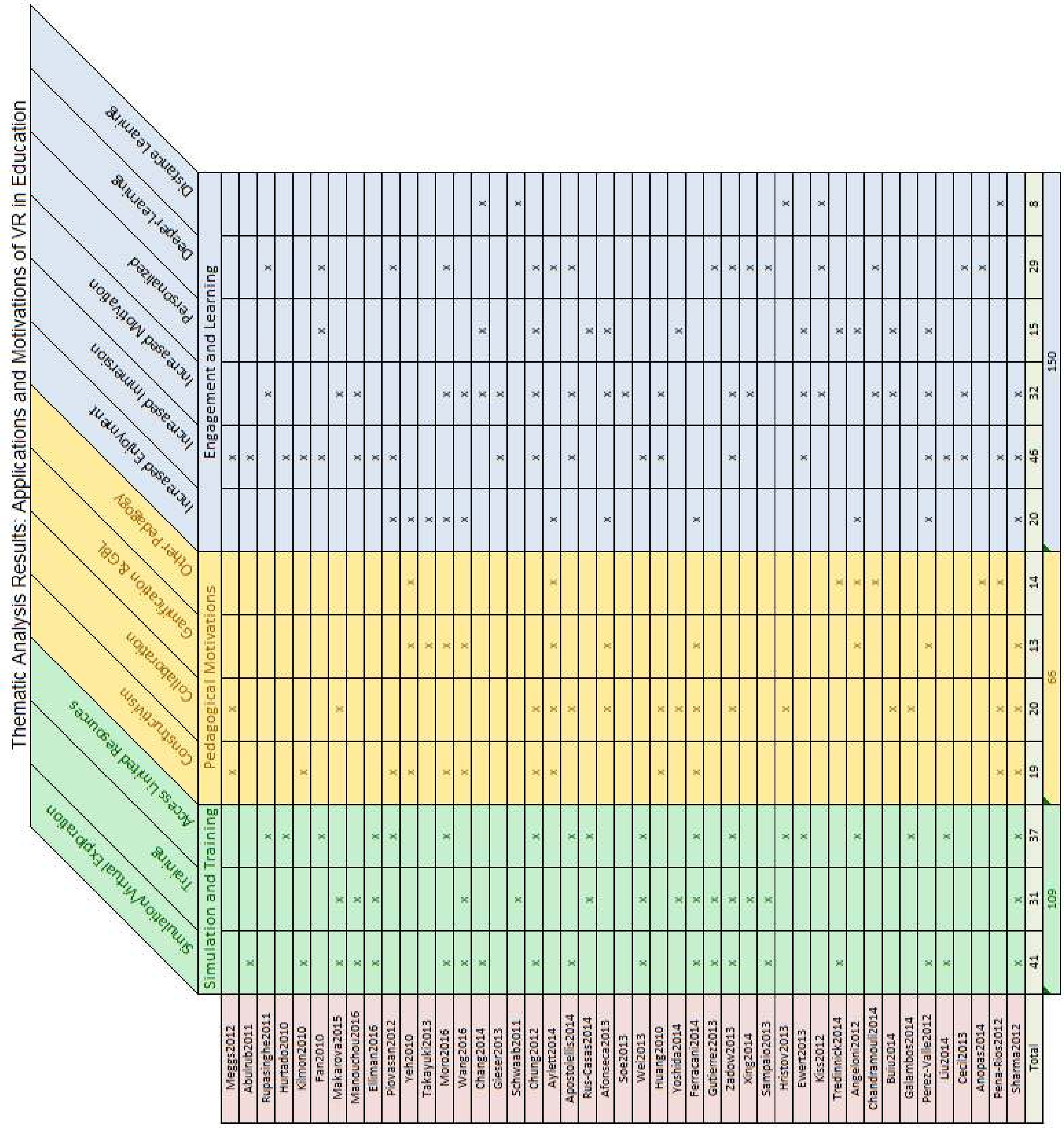


**Figure 10. Applications and motivations of VR in education, papers 45-90**
**(Full results of the thematic analysis performed on 90 papers)**

**Thematic Analysis Results: Problems with VR in Education**

| | Overhead | | Input Problems | | | Output Problems | | | Usefulness | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Training | Cost | Input Hardware Usability | Lack of Feedback | Recognition Innaccuracies | Motion Sickness | Insufficient Realism | Software Usability | Ineffective | No Reported Issues | Lack of Engagement |
| Schlacht2017 | | | | | | | | | x | | x |
| Nolin2016 | | | | | | x | | | | | |
| Fabola2016 | | x | | | x | | x | | | | |
| Staurset2016 | | x | | | x | | x | x | | | |
| Le2014 | x | | | | x | | x | | x | | |
| Ridene2015 | | | | | | | | x | | | |
| Falah2014 | | | | | | | | x | | | |
| Morales2013 | | | | | | | | x | | | |
| Chen2012 | | | | | | | | | | | x |
| Sun2010 | x | x | | | | | | x | | | |
| Deb2016 | | x | | | | | | x | | | |
| Huang2016 | | x | | | | | | | x | | |
| Rahim2012 | | | x | | | x | | x | | | |
| Tsai2012 | | | | | | | | | | | x |
| Meggs2012 | x | x | | | | | | x | | | x |
| Rupasinghe2011 | | | | | | | | | | x | |
| Fan2010 | | | | | | | | | | | x |
| Manouchou2016 | x | | | | | | x | | | | |
| Chang2014 | | | | x | x | | | | | | x |
| Cheung2013 | | | | x | x | | | | | | x |
| Cuccurullo2010 | | x | | | | | | x | | | |
| Gieser2013 | | | x | | x | | | | | | |
| Gomes2012 | | | | | | | | | | | x |
| Hsiaoa2010 | | | | | | | | x | | | |
| Hsieh2010 | | | | | | | x | x | | | x |
| Ip2010 | | | | | | | | x | | | x |
| Schwaab2011 | | | | | | | x | x | x | | |
| Wang2013 | x | | | | | | | x | | | |
| Wiecha2010 | x | x | | | | | | x | | | |
| Chung2012 | | | | | | | | | | x | |
| Aylett2014 | | | x | | | | x | | x | | |
| Apostolellis2014 | | | x | | | | | x | | | x |
| Rus-Casas2014 | | | | | | | | x | x | | |
| Afonseca2013 | | | x | | | | | | | | |
| Soe2013 | | x | x | | x | | | | | | |
| Count | 6 | 9 | 6 | 2 | 7 | 2 | 7 | 17 | 6 | 2 | 11 |
| | 15 | | 15 | | | 26 | | | 19 | | |

**Figure 9. Problems with VR in education**
**(Full results of the second thematic analysis performed on 35 papers)**

**Virtual Reality Peripherals Matrix**

**Functionality**

**Input Peripherals**

| Technology | Bimanual | Markerless | Consumer-ready | Upper-body tracking | Lower-body tracking | Tethered | Graspable | Freehand | Haptic Feedback |
|---|---|---|---|---|---|---|---|---|---|
| Kinect | Yes | Yes | Yes | Yes | Yes | No | No | Yes | No |
| Oculus Touch | Yes | No | Yes | No | No | No | Yes | No | Yes |
| Lighthouse (HTC Vive) | Yes | No | Yes | No | No | No | Yes | No | Yes |
| Leap Motion | Yes | Yes | Yes | No | No | No | No | Yes | No |
| PS Move | Yes | No | Yes | No | No | Yes | Yes | No | Yes |
| Wii | Yes | No | Yes | No | No | No | Yes | No | Yes |
| Razer Hydra | Yes | Yes | Yes | No | No | Yes | Yes | No | No |
| STEM VR | Yes | Yes | No | Yes | Optional | No | Yes | No | Yes |
| Control VR | Yes | Yes | No | Yes | No | Yes | No | Yes | Yes |
| Myo Armband | Yes | Yes | No | No | No | No | No | Yes | No |
| PrioVR | Yes | Yes | No | Yes | Optional | Yes | No | Yes | No |
| Mouse | No | N/A | Yes | No | No | Varies | Yes | No | No |
| Keyboard | Yes | N/A | Yes | No | No | Varies | N/A | No | No |
| Tablet | Yes | N/A | Yes | No | No | No | Yes | No | Varies |
| Tangibles | N/A | No | Yes | No | No | No | Yes | No | No |
| Cyberith | N/A | N/A | No | No | Yes | Yes | N/A | N/A | No |
| Virtuix Omni | N/A | N/A | No | No | Yes | Yes | N/A | N/A | No |
| Livescribe 3 | No | N/A | Yes | N/A | N/A | No | Yes | No | No |
| Voice Recognition | N/A | N/A | N/A | N/A | N/A | No | No | N/A | N/A |
| Human Hand | Yes | N/A | N/A | N/A | N/A | No | No | Yes | N/A |

**Output Peripherals**

| Technology | Consumer-ready | Motion Tracking | Multi-user | Full Immersion*1 | Built-in Microphone | Built-in Speakers |
|---|---|---|---|---|---|---|
| Oculus Rift | Yes | Yes | No | Yes | Yes | Yes |
| PlayStation VR | Yes | Yes | No | Yes | No | No |
| HTC Vive | Yes | Yes | No | Yes | Yes | No |
| Mechdyne CAVE2 | Yes | Yes | Yes | Yes | No | Yes |
| Desktop Monitor | Yes | No | No | No | Varies | Varies |

**Figure 10. The Virtual Reality Peripherals Matrix, Part 1**
**(Functionalities and/or capabilities of input and output hardware peripherals of VR)**

| Metrics | | | | | | | |
|---|---|---|---|---|---|---|---|
| Input Peripherals | | | | | | | |
| Technology | Cost ($USD)[ab] | Input Type | DoF[i] | Accuracy[f] | Latency | | |
| Kinect | 109.99 | Gestural | 6 | 3mm[h] [Khoshelham2012] | 146ms [Livingston2012] | | |
| Leap Motion | 79.99 | Gestural | 6 | 0.7mm [Weichert2013] | 10ms [Eduardo2013] | | |
| PS Move | 79.99 | Gestural | 6 | | 115ms (Tanaka2012] | | |
| Wii | 25 | Gestural | 6 | | 143ms [Tanaka2012] | | |
| Razer Hydra | N/A Discontinued | Gestural | 6 | 1mm [Razer2014] | | | |
| STEM VR | 219.98+[c] | Gestural | 6 | 1mm [Tracking2014] | 10ms [STEM2014] | | |
| Control VR | 600[d] | Gestural | 6 | | 50-60 [Kickstarter2014] | | |
| Myo Armband | 150 | Gestural | N/A | | | | |
| PrioVR | 289[e] | Gestural | 6 | 1° [YEI_Paul2014_2] | 7.5ms [YEI_Paul2014] | | |
| Mouse | Varies | Mouse | 2 | Varies | Varies | | |
| Keyboard | Varies | Keyboard | N/A | N/A | Varies | | |
| Tablet | Varies | Tablet PC | N/A | Varies | Varies | | |
| Tangibles | Varies | Tangible | N/A | Varies | Varies | | |
| Cyberith | N/A | Gestural | N/A | | | | |
| Virtuix Omni | 499 | Gestural | N/A | | | | |
| Livescribe 3 | 150 | Pen | 2 | N/A | High (>1 second) | | |
| Voice Recognition | N/A | Voice | N/A | N/A | N/A | | |
| Human Hand | N/A | N/A | 6 | 0.4mm [Weichert2013] | N/A | | |
| Output Peripherals | | | | | | | |
| Technology | Cost ($USD) | Output Type | DoF | Resolution | Latency | Screen Type | Refresh Rate |
| Oculus Rift | 599-798 | Head-mounted Display | 6 | 1080 x 1200 per eye | 20ms | OLED | 90Hz |
| PlayStation VR | 400 | Head-mounted Display | 6 | 960 x RGB x 1080 per eye | 18ms | OLED | 90-120Hz |
| HTC Vive | 690 | Head-mounted Display | 6 | 1080 x 1200 per eye | 22ms | OLED | 90Hz |
| Mechdyne CAVE2 | Varies (High) | Projected | 6 | Varies (High) | | N/A | Varies |
| Desktop Monitor | Varies | Screen | N/A | Varies | Varies | Varies | Varies |

**Figure 11. Virtual Reality Peripherals Matrix, Part 2**
**(Functionalities and/or capabilities of input and output hardware peripherals of VR)**

*a.* Costs taken from the products official websites unless otherwise stated. Prices and discounts excluded. Prices recorded on 10/05/2015.

*b.* Prices refer to the cost of the peripheral, prices of base hardware (such as the Wii or PlayStation console) not included.

*c.* Price dependent on number of trackers purchased. 5-tracker system costs $579.99

*d.* Includes 2 arm and upper body tracking.

*e.* Price dependent on number of sensors. 17-sensor system costs $429.

*f.* Metrics obtained from the products websites or developer comments. Otherwise from peer reviewed studies (referenced accordingly).

*h.* 3mm-70mm (distance dependent).

*i.* Degrees of Freedom (DoF).

## References

Abdul Rahim, E., Duenser, A., Billinghurst, M., Herritsch, A., Unsworth, K., Mckinnon, A., & Gostomski, P. (2012). A desktop virtual reality application for chemical and process engineering education. *Proceedings of the 24th Australian Computer-Human Interaction Conference* (pp. 1–8). New York: ACM Press. http://doi.org/10.1145/2414536.2414537.

Afonseca, C., & Badia, S. B. i. (2013). Supporting collective learning experiences in special education. *Proceedings of the IEEE 2nd International Conference on Serious Games and Applications for Health (SeGAH)* (pp. 1–7). Los Alamitos: IEEE Press.

Allison, D., & Hodges, L. F. (2000). Virtual reality for education?. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology* (pp. 160-165). Seoul: ACM Press. http://doi.org/10.1145/502390.502420.

Angeloni, I., Bisio, F., De Gloria, A., Mori, D., Capurro, C., & Magnani, L. (2012). A Virtual Museum for Flemish artworks. A digital reconstruction of Genoese collections. *Proceedings of the 18th International Conference on Virtual Systems and Multimedia* (pp. 607–610). Los Alamitos: IEEE Press.

Anopas, D., & Wongsawat, Y. (2014). Virtual reality game for memory skills enhancement based on QEEG. *Proceedings of the 7th 2014 Biomedical Engineering International Conference* (pp. 1–5). Los Alamitos: IEEE Press.

Apostolellis, P., & Bowman, D. A. (2014). Evaluating the effects of orchestrated, game-based learning in virtual environments for informal education. *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology - ACE '14* (pp. 1–10). New York, USA: ACM Press.

Auld, L. W. S., & Pantelidis, V. S. (1994). Exploring virtual reality for classroom use. *TechTrends*, 39(1), 29–31.

Avila, L., & Bailey, M. (2014). Virtual Reality for the Masses. *IEEE Computer Graphics and Applications*, 5. Retrieved 2 December 2017, from http://www.computer.org/csdl/mags/cg/2014/05/mcg2014050103.pdf.

Budziszewski, P. (2013). A Low Cost Virtual Reality System. *Physical Therapy*, 88(10), 32–39.

Buiu, C., & Gansari, M. (2014). Designing robotic avatars in Second Life - A tool to complement robotics education. *Proceedings of the 2014 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1016–1018). Los Alamitos: IEEE Press.

Burdea, G., & Coiffet, P. (2003). Virtual Reality Technology. *Presence: Teleoperators and Virtual Environments*, 12(6), 663–664.

Carmody, T. (2010). *Why "Gorilla Arm Syndrome" Rules Out Multitouch Notebook Displays*. Retrieved 2 December 2017, from http://www.wired.com/2010/10/gorilla-arm-multitouch.

Cecil, J., Ramanathan, P., & Mwavita, M. (2013). Virtual Learning Environments in engineering and STEM education. *Proceedings of the 2013 IEEE Frontiers in Education Conference* (pp. 502–507). Los Alamitos: IEEE Press.

Chandramouli, M., Zahraee, M., & Winer, C. (2014). A fun-learning approach to programming: An adaptive Virtual Reality (VR) platform to teach programming to engineering students. *Proceedings of the IEEE International Conference on Electro/Information Technology* (pp. 581–586). Los Alamitos: IEEE Press.

Chang, Y.-J., Wang, C.-C., Luo, Y.-S., & Tsai, Y.-C. (2014). Kinect-based rehabilitation for young adults with cerebral palsy participating in physical education programs in special education school settings. *Proceedings of the World Conference on Educational Multimedia, Hypermedia and Telecommunications* (pp. 792–795). Retrieved 2 December 2017 from http://www.editlib.org/p/147583.

Cheung, S. K. S., Fong, J., Fong, W., Wang, F. L., & Kwok, L. F. (Eds.) (2013). *Hybrid Learning and Continuing Education (Vol. 8038)*. Berlin, Heidelberg: Springer.

Chien, S.-C., Chung, Y.-W., Lin, Y.-H., Huang, J.-Y., Chang, J.-T., He, C.-Y., & Cheng, Y.-W. (2012). Mackay campus of the environmental education and digital cultural construction-The Application of 3D Virtual Reality. *Proceedings of the Fourth International Conference on Digital Image Processing (Vol. 8334)*.

Chung, L.-Y. (2012). Virtual Reality in college English curriculum: Case study of integrating second life in freshman English course. *Proceedings of the 26th International Conference on Advanced Information Networking and Applications Workshops* (pp. 250–253). Los Alamitos: IEEE Press.

Control-VR. (2014). *Kickstarter - Control VR- The Future of Virtual Reality, Animation & more by The Control VR Team*. Retrieved 15 October 2014, from https://www.kickstarter.com/projects/controlvr/control-vr-motion-capture-for-vr-animation-and-mor.

Cuccurullo, S., & Francese, R., Passero, I., Tortora, G. (2010). ReW: Reality Windows for Virtual Worlds. *Proceedings of the 18th International Conference on Computers in Education* (pp. 3-10). Serdang, Selangor, Malaysia: Faculty of Educational Studies, Universiti Putra Malaysia.

Cybreth. (2013). *Kickstarter-Cyberith Virtualizer- Immersive Virtual Reality Gaming by Cyberith*. Retrieved 4 March 2015, from https://www.kickstarter.com/projects/1259519125/cyberith-virtualizer-immersive-virtual-reality-gam.

Deb, S., & Ray, A. B. (2016). Smartphone Based Virtual Reality Systems in Classroom Teaching -a study on the effects of learning outcome. *Proceedings of the IEEE Eighth International Conference on Technology for Education* (pp. 68–71). Los Alamitos: IEEE Press.

Dewey, J. (1985). *Democracy and education, 1916*. Il: Southern Illinois University Press Carbondale.

Ewert, D., Schuster, K., Johansson, D., Schilberg, D., & Jeschke, S. (2013). Intensifying learner's experience by incorporating the virtual theatre into engineering education. In *2013 IEEE Global Engineering Education*

*Conference (EDUCON)* (pp. 207–212). Retrieved 20 December 2017 from http://doi.org/10.1109/EduCon.2013.6530107.

Fabola, A., & Miller, A. (2016). Virtual Reality for early education: A study. In C. Allison, L. Morgado, J. Pirker, D. Beck, J. Richter & C. Gütl (Eds.) *Immersive Learning Research Network (iLRN 2016). Communications in Computer and Information Science* (vol. 621, pp. 59–72). CA: Springer.

Falah, J., Khan, S., Alfalah, T., Alfalah, S. F. M., Chan, W., Harrison, D. K., & Charissis, V. (2014). Virtual Reality medical training system for anatomy education. *Proceedings of the* 2014 *Science and Information Conference* (pp. 752–758). Retrieved 20 December 2017, from http://doi.org/10.1109/SAI.2014.6918271.

Ferracani, A., Pezzatini, D., & Del Bimbo, A. (2014). A natural and immersive virtual interface for the surgical safety checklist training. In S. Göbel & W. Effelsberg (Eds.) *Proceedings of the 2014 ACM International Workshop on Serious Games* (pp. 27–32). New York, USA: ACM Press.

Galambos, P., Baranyi, P., & Rudas, I. J. (2014). Merged physical and virtual reality in collaborative virtual workspaces: The VirCA approach. In B. Fahimi & G. Capolino (Eds.), *Proceedings of the 40th Annual Conference of the IEEE Industrial Electronics Society* (pp. 2585-2590). Dallas, TX, USA: IEEE.

Gieser, S. N., Becker, E., & Makedon, F. (2013). Using CAVE in physical rehabilitation exercises for rheumatoid arthritis. In F. Makedon (Ed.), *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments* (pp. 1–4). New York: ACM Press.

Gomes, A., Oh, H., Chisik, Y., & Chen, M. (2012). Ilha Musical: A CAVE for nurturing cultural appreciation. In H. Schelhowe (Ed.), *Proceedings of the 11th International Conference on Interaction Design and Children* (p. 232-235). Bremen, Germany: ACM Press.

Gutierrez-Maldonado, J., & Ferrer-Garcia, M. (2013). Are virtual patients effective to train diagnostic skills? In N. M. Thalmann (Ed.), *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology* (p. 267). New York: ACM Press.

Haluck, R. S. (2000). Computers and Virtual Reality for Surgical Education in the 21st Century. *Archives of Surgery*, 135(7), 786.

Horowitz, K. (2004). *Sega VR: Great Idea or Wishful Thinking?* Retrieved 19 May 2015, from http://web.archive.org/web/20100114191355/http://sega-16.com/feature_page.php?id=5&title=Sega.

Hristov, G., Zahariev, P., Bencheva, N., & Ivanov, I. (2013). Designing the next generation of virtual learning environments — Virtual laboratory with remote access to real telecommunication devices. In G. Papadourakis (Ed.), *Proceedings of the 24th International Conference on European Association for Education in Electrical and Information Engineering* (pp. 139–144). Chania, Greece: IEEE.

Hsiaoa, I., Lia, I., & Lanb, Y. (2010). *Development of a virtual campus on Second Life: A case study of NCU Wonderland*. Retrieved 20 December 2017, from http://hub.hku.hk/bitstream/10722/136144/1/re01.htm#page=262.

Hsieh, P., Wub, Y., & Mac, F. (2010). A study of visitor's learning needs and visit satisfaction in real and second life museums. In T. Hirashima, A. F. Mohd AYUB, l. Kwok, S. Wong, S.C. Kong & F. Yu (Eds.), *Workshop Proceedings of the 18th International Conference on Computers in Education* (pp. 248-255). Malaysia: Faculty of Educational Studies, Universiti Putra Malaysia.

Huang, H.-M., Liaw, S.-S., & Lai, C.-M. (2016). Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection-based display systems. *Interactive Learning Environments*, 24(1), 3–19.

Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3), 1171–1182.

Hurtado, C. V., Valerio, A. R., & Sanchez, L. R. (2010). Virtual reality robotics system for education and training. *Proceedings of the 2010 IEEE Electronics, Robotics and Automotive Mechanics Conference* (pp. 162–167). Cuernavaca, Morelos, México: IEEE.

Ip, H., Byrne, J., & Cheng, S. (2010). Smart Ambience for Affective Learning (SAMAL): Instructional Design and Evaluation. In T. Hirashima, A. F. Mohd AYUB, l. Kwok, S. Wong, S.C. Kong & F. Yu (Eds.), *Workshop Proceedings of the 18th International Conference on Computers in Education* (pp. 212-220). Malaysia: Faculty of Educational Studies, Universiti Putra Malaysia.

Jacobson, J., Holden, L., Studios, F., & Toronto, C. (2005). The Virtual Egyptian Temple. *Proceedings of the World Conference on Educational Media, Hypermedia & Telecommunications (ED-MEDIA)*. Retrieved 20 December 2017, from https://pdfs.semanticscholar.org/e4cb/929440177f9ea9a87ac5eacb6f4f33977e98.pdf.

Johnson, A., Roussos, M., Leigh, J., & Vasilakis, C. (1998). *The NICE Project: Learning Together in a Virtual World*. Retrieved 20 December 2017, from http://evlweb.eecs.uic.edu/aej/papers/vrais98.pdf.

Kaufmann, H., & Meyer, B. (2009). Physics education in Virtual Reality: An example. *Themes in Science and Technology Education*, 2(1-2), 117-130.

Kiss, G. (2012). Using web conference system during the lessons in higher education. *Proceedings of the 2012 International Conference on Information Technology Based Higher Education and* Training (pp. 1–4). Istanbul: IEEE.

Kitchenham, B. (2004). Procedures for performing systematic reviews. Retrieved 20 December 2017, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.122.3308&rep=rep1&type=pdf.

Kushner, D. (2014). Virtual reality's moment. *IEEE Spectrum*, 51(1), 34–37.

Le, Q. T., Pedro, A., & Park, C. S. (2014). A social Virtual Reality based construction safety education system for experiential learning. *Journal of Intelligent & Robotic Systems*, 79(3–4), 487–506

Limniou, M., Roberts, D., & Papadopoulos, N. (2008). Full immersive virtual environment CAVE TM in chemistry education. *Computers & Education*, 51(2), 584-593.

Meggs, S. M., Greer, A., & Collins, S. (2012). Virtual Reality in interior design education: Enhanced outcomes through constructivist engagement in Second Life. *International Journal of Web-Based Learning and Teaching Technologies*, 7(1), 19–35.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, 70, 29–40.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999-2009). *Computers and Education*, 56(3), 769-780.

Moro, C., Stromberga, Z., Raikos, A., & Stirling, A. (2016). Combining virtual (Oculus Rift & Gear VR) and augmented reality with interactive applications to enhance tertiary medical and biomedical curricula. In M. Aoki & Z. Pan (Eds.) *Proceedings of the SIGGRAPH ASIA 2016 Symposium on Education* (pp. 1–2). NY: ACM.

Mossel, A., & Kaufmann, H. (2013). Wide area optical user tracking in unconstrained indoor environments. *Proceedings of the 23rd International Conference on Artificial Reality and Telexistence* (pp. 108–115). http://doi.org/10.1109/ICAT.2013.6728915.

Naone, E. (2007). *Virtual Labor Lost: MIT Technology Review*. Retrieved 19 November 2014, from http://www.technologyreview.com/news/409147/virtual-labor-lost.

Nolin, P., Stipanicic, A., Henry, M., Lachapelle, Y., Lussier-Desrochers, D., Rizzo, A., & Allain, P. (2016). ClinicaVR: Classroom-CPT: A virtual reality tool for assessing attention and inhibition in children and adolescents. *Computers in Human Behavior*, 59, 327–333.

Oculus (2012). *Kickstarter -- Oculus Rift: Step into the Game by Oculus*. Retrieved 4 March 2015, from https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game.

Omni (2014). *Kickstarter -- Omni: Move Naturally in Your Favorite Game by Virtuix*. Retrieved 4 March 2015, from https://www.kickstarter.com/projects/1944625487/omni-move-naturally-in-your-favorite-game.

Page, R. (2000). Brief history of flight simulation. *Proceedings of the SimTecT 2000* (pp. 1–11). http://doi.org/10.1.1.132.5428.

Panteldis, V. (2009). Reasons to use Virtual Reality in education and training courses and a model to determine when to use Virtual Reality. *Themes in Science and Technology Education*, 2(1-2), 59-70.

Paterson, S. (2015). *2560 x 1440 Very Likely The Oculus Rift Consumer (CV1) Resolution | VRCircle*. Retrieved 16 March 2015, from http://www.vrcircle.com/post/2560-x-1440-very-likely-the-oculus-rift-consumer-cv1-resolution#.VG48vhcTL00.reddit.

Pena-Rios, A., Callaghan, V., Gardner, M., & Alhaddad, M. J. (2012). Remote mixed reality collaborative laboratory activities: Learning activities within the InterReality portal. In Y. Li, Y. Zhang & N. Zhong (Eds.), *Proceedings of the 2012 IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology* (Vol. 3, pp. 362–366). Macau, China: IEEE.

Perez-Valle, A., & Sagasti, D. (2012). A novel approach for tourism and education through virtual Vitoria-Gasteiz in the 16th century. *Proceedings of the 18th International Conference on Virtual Systems and Multimedia* (pp. 615–618). Milan, Italy: IEEE.

Piovesan, S. D., Passerino, L. M., & Pereira, A. S. (2012). Virtual Reality as a tool in the education. In D. G Sampson, J. M. Spector, D. Ifenthaler & P. Isaías (Eds.), *IADIS International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2012)* (pp. 295-298). Madrid: IADIS.

PrioVR (2014). *Kickstarter -- PrioVR: Suit up. Game on by YEI Technology*. Retrieved 4 March 2015, from https://www.kickstarter.com/projects/yeitechnology/priovr-suit-up-game-on.

Rizzo, A. A., Buckwalter, J. G., Bowerly, T., Van Der Zaag, C., Humphrey, L., Neumann, U., Chua, C., Kyriakakis, C., Van Rooyen, A., & Sisemore, D. (2000). The Virtual Classroom: A Virtual Reality Environment for the assessment and rehabilitation of attention deficits. *CyberPsychology & Behavior*, 3(3), 483–499.

Rizzo, A., & Bowerly, T., Buckwalter, J.G., Klimchuk, D., Mitura, R., & Parsons, T.D. (2006). A Virtual Reality scenario for all seasons: The virtual classroom. *CNS Spectrums*, 11(1), 35-44.

Rupasinghe, T. D., Kurz, M. E., Washburn, C., & Gramopadhye, A. K. (2011). Virtual Reality training integrated curriculum: An Aircraft Maintenance Technology (AMT) education perspective. *International Journal of Engineering Education*, 27(4), 778–788.

Rus-Casas, C., Hontoria, L., Jimenez-Torres, M., Munoz-Rodriguez, F. J., & Almonacid, F. (2014). Virtual laboratory for the training and learning of the subject solar resource: OrientSol 2.0. *Proceedings of the Tecnologias Aplicadas a la Ensenanza de la Electronica (Technologies Applied to Electronics Teaching)* (pp. 1–6). Bilbao, Spain: IEEE. http://doi.org/10.1109/TAEE.2014.6900129.

Schwaab, J., Kman, N., Nagel, R., Bahner, D., Martin, D. R., Khandelwal, S., Vozenilek, J., Danforth, D. R., & Nelson, R. (2011). Using Second Life virtual simulation environment for mock oral emergency medicine examination. *Academic Emergency Medicine : Official Journal of the Society for Academic Emergency Medicine*, 18(5), 559–62.

Sharma, S., Agada, R., & Ruffin, J. (2013). Virtual reality classroom as a constructivist approach. *Proceedings of the 2013 IEEE Southeastcon* (pp. 1–5). Jacksonville, FL, USA: IEEE. http://doi.org/10.1109/SECON.2013.6567441.

Sharma, S., & Otunba, S. (2012). Collaborative virtual environment to study aircraft evacuation for training and education. *Proceedings of the 2012 International Conference on Collaboration Technologies and Systems (CTS)* (pp. 569–574). Denver, CO, USA: IEEE. http://doi.org/10.1109/CTS.2012.6261107.

Song, P., Xu, S., Fong, W. T., Chin, C. L., Chua, G. G., & Huang, Z. (2012). An immersive VR system for sports education. *IEICE Transactions on Information and Systems*, E95–D, 1324–1331.

Staurset, E., & Prasolova-Førland, E. (2016). Creating a smart Virtual Reality simulator for sports training and education. In V. L. Uskov, R. J. Howlett, L. C. Jain (Eds.), *Smart Education and E-Learning 2016* (pp. 423–433). Switzerland: Springer.

Sun, K. T., Lin, C. L., & Wang, S. M. (2010). A 3-D Virtual Reality model of the sun and the moon for e-learning at elementary schools. *International Journal of Science and Mathematics Education*, 8(4), 689–710.

Sutcliffe, A. (2003). *Multimedia and virtual Reality: Designing multisensory user interfaces*. England: Psychology Press.

Takala, T. (2014). RUIS: a toolkit for developing virtual reality applications with spatial interaction. In A. Wilson (Ed.), *Proceedings of the 2nd ACM Symposium on Spatial Interaction* (pp. 94-103). NY: ACM.

Tredinnick, R., Vanderheiden, J., Suplinski, C., & Madsen, J. (2014). CAVE visualization of the IceCube neutrino detector. In S. Coquillart, K. Kiyokawa, J. E. Swan II & D. Bowman (Eds.), *Proceedings of the 2014 IEEE Virtual Reality* (pp. 117–118). Minneapolis, MN, USA: IEEE.

Tsaramirsis, G., Buhari, S., AL-Shammari, K. O., Ghazi, S., Nazmudeen, M. S., & Tsaramirsis, K. (2016). Towards simulation of the classroom learning experience: Virtual Reality approach. In H. Mn (Ed.), *The 10th Indiacom - 2016 3rd International Conference on Computing for Sustainable Global Development* (pp. 1343–1346). New Delhi, India: IEEE.

von Zadow, U., Buron, S., Sostmann, K., & Dachselt, R. (2013). The SimMed experience. In A. Quigley & G. Jacucci (Eds.), *Proceedings of the 2013 ACM international conference on interactive tabletops and surfaces* (pp. 297–300). New York: ACM.

Wang, J.-F., & Lau, R. (Eds.). (2013). *Using Kinect for holodeck classroom: A framework for presentation and assessment (Vol. 8167)*. Berlin, Heidelberg: Springer.

Wei, W., Dongsheng, L., & Chun, L. (2013). Fixed-wing aircraft interactive flight simulation and training system based on XNA. In X. Zhang, Z. Zhou, Q. Wang & X. Luo (Eds.), *Proceedings of the 2013 International Conference on Virtual Reality and Visualization* (pp. 191-198). Xian, Shaanxi, China: IEEE.

West, N. (1995). *NEXT Generation Issue #6 June 1995: AOU: coin-op houses unveil '95 line-up*. Retrieved 19 May 2015, from https://archive.org/details/nextgen-issue-006#page/n23/mode/2up.

Wiecha, J., Heyden, R., Sternthal, E., & Merialdi, M. (2010). Learning in a virtual world: Experience with using Second Life for medical education. *Journal of Medical Internet Research*, 12(1), e1.

Yoshida, S., Kihara, K., Takeshita, H., & Fujii, Y. (2014). Instructive head-mounted display system: pointing device using a vision-based finger tracking technique applied to surgical education. *Wideochirurgia Inne Techniki Małoinwazyjne*, 9(3), 449–52.

Zavalani, O., & Spahiu, A. (2012). Use curiosity for virtual reality "as a hook" in the engineering education. In *Proceedings of the 15th International Conference on Interactive Collaborative Learning* (pp. 1–4). Villach, Austria: IEEE.

Zhang, L., & Liu, Q. (2012). Application of simulation and Virtual Reality to physical education and athletic training. *Lecture Notes in Computer Science*, 7145 LNCS, 24–33.

Zita Sampaio, A., & Viana, L. (2013). Virtual Reality used as a learning technology: Visual simulation of the construction of a bridge deck. *Proceedings of the 8th Iberian Conference on Information Systems and Technologies* (pp. 1–5). Lisboa: IEEE.

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