Virtual Reality & Augmented Reality in primary education

-- a literary review and exploratory research --

Robin de Lange & Maarten Lodewijk

Translation by Nesse van der Meer

January 2017

1 Introduction

During the *Kennisrotonde* of the Netherlands Initiative for Education Research (NRO), board members of several primary schools posed a number of questions regarding the use of Virtual Reality (VR) and Augmented Reality (AR) in primary education. In this report, we will answer three of these questions:

1. Have there been previous attempts at applying AR and VR to primary education and, if so, how did these fare and what results did they provide?
2. Has there been prior research on the use of AR and VR in education in relation to learning efficiency?
3. What explanation does brain learning offer for the relation between the use of AR and VR in education and learning efficiency?

Simultaneously, we aim to provide an overview of the current state of technology, prior educational research, promising applications and recommendations for improving learning effects. While this overview will focus on primary education, examples from other areas will occasionally be discussed.

2 Research methods & structure

Although similarities between the two are apparent, AR and VR simultaneously differ distinctively in a number of ways. To emphasize these distinctions, the decision was made to discuss VR and AR separately in this report.

Currently, technical development in the field of both AR and VR is progressing rapidly. VR in particular has seen some significant advancements during the past four years.
In order to provide a coherent overview of AR and VR, we will discuss the state-of-the-art of both technologies, as well as their different forms of appearance and our interpretation of related concepts.

A bibliographic study on prior scientific literature will be conducted so as to acquire an impression of what is currently known about the use of AR and VR as educational tools. This knowledge will then be used to present a comprehensive analysis of both technologies. Additionally, any results related to the learning efficiency of AR and VR (as discussed in the available literature) will be highlighted.

Development of AR and VR applications is primarily done by independent developers, startup companies or more professional, commercial organizations. Since scientific research amongst these parties is rarely self-evident, academic literature on the subject is scarce. Furthermore, existing literature on the educational use of AR and VR often fails to discuss the more promising applications that both technologies have to offer.

The exploratory research conducted by the lead author of this study for his promotion is also an important form of input here.

After reviewing current results on the learning efficiency of both technologies, a qualitative analysis of the potential behind AR and VR as educational tools will be given. A significant portion of this analysis will be based on the exploratory research conducted by the lead author for his PhD research.

The research conducted for this study primarily consisted of (1) extensive literary research, (2) interviews with teachers, educators, schools, educational innovators and -companies, (3) personal experience with the development of AR- and VR-applications and (4) personal experience with the teaching of multidisciplinary research courses at the Leiden University, during which students were tasked with developing VR applications intended for educational purposes (de Lange, Virtual Reality for Science & Education 2016 - a review, 2016).

Furthermore, in order to formulate an answer to question 1 of this study, employees of the NRO Kennisrotonde conducted interviews with two primary school teachers who use AR and VR in their classes.

3 Virtual Reality

3.1 History and techniques

Several interpretations of VR have been established during the past decades in both science- and popular literature. To understand the different interpretations and to clarify our choice herein it is good to discuss some elements of the history of VR.

The concept of entering a completely different world through a medium has been around for some time. Panoramic paintings from the 19th century, for example, can be considered the first attempts to create the illusion of presence. Similarly, stereoscopic photography can be seen as a significant contribution to the development of VR.

A majority of the papers examined for this study refer to the *Sensorama*, made by Morton Heilig in the fifties of the last century. After being seated in the installation, users were shown 3D videos, shot with wide-angle lenses. Additionally, the installation made use of fans, different scents and a vibrating chair. The Headsight, released in 1961, was the first Head Mounted Display (HMD) with head-tracking, though it was still using video footage. By means of magnetic tracking, a camera would follow users' head movements, allowing them to look around in a separate space.

During the 1960's and 1970's, new ideas related to graphical interfaces were conceived for innovative, electronic computers: gigantic machines of which only a small number existed in the world. The grand, poetic ideas conceived during this era are still inspiring today, albeit somewhat naïve. For example, Ivan Sutherland fantasized about the concept of the *Ultimate Display*, a room where all matter could be controlled by a computer, twenty years before the Graphical User Interface of Apple's *Lisa*. The *Ultimate Display* would provide us with intuitions about unknown physical systems:

‘A display connected to a digital computer gives us a chance to gain familiarity with concepts not realizable in the physical world. It is a looking glass into a mathematical wonderland.’ (Sutherland, 1964)

Near the end of the 1980’s, development of three-dimensional computer-interfaces were advancing rapidly. The first commercial HMDs were released to market, the term “Virtual Reality” gained popularity and a massive VR-hype was beginning to take hold. The Virtual Reality-industry was about to become a billion-dollar-industry; expectations were high. In retrospect, the graphical capabilities of the technology available at that time were severely lacking, as can be seen in the video lecture (Voshart, 2015), which showcases several applications. Expectations could not be met and as such, VR entered the “Trough of Disillusionment” of the Gartner Hype Cycle. After the failure of Nintendo’s *Virtual Boy*, a long radio silence ensued in the world of VR.

For almost two decades, VR received little attention in the media, though advancements in the field were being made. Experiments with specialistic and valuable applications for entertainment, training purposes and engineering were being conducted. An important platform in development at the time was the CAVE: a collection of VR-rooms accessible to multiple users, with several projection-screens functioning as an alternative for HMDs.

Simultaneously, the graphical capabilities of the average computer were advancing swiftly. The video game-industry was growing rapidly and games were being used as an educational tool on a much larger scale. In academic literature, an alternative interpretation of VR, which now also included interactive virtual worlds on screens, was beginning to take hold. Other authors have since made the distinction between immersive and non-immersive VR.

The announcement of the Kickstarter campaign for the Oculus Rift in 2012 came as a surprise to many. After a long period of little media attention, a Virtual Reality-headset far more advanced than anything else on the market (and with a price considered reasonable by most consumers) had suddenly become available. This sudden advancement led to an increase in both the development and market growth of VR. The arrival of Google Cardboard illustrated that just (the technology behind) an advanced smartphone was sufficient for experiencing VR. In the field of “Mobile VR”, the Gear VR and the Google Daydream (available soon) currently offer the best experience. In the field of “Desktop VR”, the Oculus Rift and HTC Vive are currently considered state-of-the-art.

A major difference between the currently-available VR experiences is the level of interactivity. Compared to the Desktop VR-platform, Mobile VR shows fewer possibilities in interactivity. While the HMDs of Mobile VR detect the orientation of the head and allow the use of touchscreens (to provide some interaction), Desktop VR HMDs offer the experience of room-scale VR, allowing one to walk around in a virtual world with the use of sensors. Additionally, Desktop VR allows the use of advanced controllers that track precise hand-movements of the user, thus providing more interactive possibilities.

Additionally, the difference in level of interactivity is defined by the two different ways in which VR content is being made. With 360º (or spherical photo- and video) cameras, events in the real world can be captured in such a visual way that experiencing said events in VR correspond strongly with “being there” yourself. The interactivity of these types of experiences is often limited to determining the viewing direction. Walking around is not possible, as the 360º cameras only capture an environment from a single position. On the other hand, applications that present virtual worlds that are computer-generated, offer endless interactive possibilities. In the field of Virtual Reality, 360º videos are not always considered “true” VR.

3.2 Interpretation of Virtual Reality

For this study, we chose to focus solely on HMD-based VR. Based on our experience, HMD-based VR best corresponds with the image people currently have of Virtual Reality. Additionally, development has primarily been in the field of HMD-based VR during the past couple of years. CAVE installations and screen-based VR have not been taken into account. This allowed us to focus our study on literature published after the announcement of the Oculus Rift in 2012. Please note that 360º videos are considered VR in this study.

3.3 Search criteria and selection of literature studies

To acquire relevant literature on VR as an educational tool, we conducted a bibliographical searching procedure. With the help of application software *Publish or Perish* (Harzin, 2007), we have studied, indexed and exported article-databases *Google Scholar* and *Microsoft Academic Search* on the 15th of November, 2016. Since our interest was in articles that mainly discuss the application of VR as an educational tool, we chose to search for terms in the **title** of each article.

Considering our definition of Virtual Reality, we have selected 2012 as the oldest publication year allowed. Any duplicate results have been removed, as were any results deemed too off-topic for this study (e.g. articles on the use of VR in physical revalidation or treatment of mental illnesses).

Charts 1, 2 and 3 show a preliminary analysis of the metadata of these articles.

Chart 1

Search criteria	Number of results
allintitle: virtual AND reality AND education	165
allintitle: virtual AND reality AND learning	201
allintitle: virtual AND reality AND primary	4
allintitle: virtual AND reality AND elementary	5
allintitle: virtual AND reality AND k-12	4
allintitle: virtual AND reality AND assessment	40

Chart 2

Year of publication	Number of publications
2016 >	71
2015	79
2014	75

Chart 3

Number of citations	Number of articles
0	216
>= 1	201
>= 11	25

2013	81
2012	85
Unknown	26
Total	417

>= 31	8
>= 61	3
92	1

3.4 Learning results

Charts 1-3 show that a considerable amount of scientific articles on VR as an educational tool has become available in the past several years. The majority of the literature, however, consists of explorational (and never-cited) articles discussing the possibility of VR as a medium and/or describing VR experiences in a qualitative way. Many of these articles are technological in nature, discussing VR's possibilities for education from a technical perspective.

To better understand the effectiveness of VR as an educational tool, we have selected and closely studied 23 studies in total. Amongst these studies were often cited- or recent meta-studies (i.e. case studies suggesting concrete learning results) and often cited- or recent analyses that we deemed relevant to this study.

Of the 23 studies, the most prominently-cited one - an article in scientific journal *Computers & Education* by Merchant, Goetz, & Cifuentes, 2014 - initially seemed suitable for our study. In total, the article discusses 67 studies containing measured learning results; as such, the article concludes that concrete improvements in learning results are apparent when using VR. Unfortunately, the most recent study discussed in the article was published in November 2011. This places all 67 studies before the announcement and release of the Oculus Rift, which simultaneously explains why the article primarily discussed screen-based, non-immersive VR applications. Similarly, Y.-L. Chen's article, published in *The Asia-Pacific Education Researcher* in 2016, considers desktop-based applications to be VR applications. Although the success of 3D games and virtual worlds could provide help toward discovering the potential of immersive VR, these studies did not provide us with useful results that could help us answer our research questions.

Of the examined literature, none of the studies provided concrete learning results of the deployment of immersive VR applications in (the international equivalents of) primary- and/or secondary education.

3.5 Brain Learning and Virtual Reality

To provide an answer to this study's third research question, we have looked for studies containing "Virtual Reality" in the title and "fmri" or "neuroscience" in the subsequent text. This led to a total of 26 results, though unfortunately none of these contained any useable results for this study. This suggests that to date, no research has been conducted on the relation between brain activity and wearing a VR-headset. A probable explanation for the lack of research on this topic is the fact that electronic devices can become faulty when in close proximity with an FMRI scanner.

Regardless, this does not mean we should disregard the notion that brain research can provide knowledge on the value of VR as an educational tool. Since these two research fields are relatively new, information on both is scarce. Some relevant information is suggested in *De* *lerende mens* (2015), a book written by neuroscientists van der Helden and Bekkering. There is research that suggests an impoverished environment leads to less branched neurons. When interacting with richer environments, the neural structures in our brains become more complex. Intensive VR experiences could very well contribute to that enrichment. The danger of cognitive overload, however, should not be ignored, as Pedro de Bruyckere stresses in *Virtual Reality in het onderwijs* (Kennisnet, 2016).

As a movement, "embodied cognition" is gaining popularity, with its support continuing to grow ever more by research on brain activity. The importance of our body in understanding the world is a focal point to this movement. A majority of the complex, language-like concepts we use, seem to be based on patterns in our bodily activity (Johnson, 2007). This physicality could be used in interactive VR environments as it could help the user better understand abstract information by playing with it.

Neuroscientific research can contribute substantially towards educational research, as well as research towards VR as an educational tool. At the same time, we remain critical towards the added value of this very costly research method. Or, as Daniel T. Willingham ponders in his *When can you trust the experts*: 'do we need the brain for the claim?'

3.6 Learning results in the future?

The literature used for this study did not provide us with concrete answers to the second and third research questions. An important follow-up question would be if we can expect VR to show positive learning results in primary education in the foreseeable future. Before answering this question, it is necessary to discuss some remarks.

VR HMDs have only recently become widely available for consumers. Furthermore, it is currently too early to formulate any conclusions regarding the influence of VR on learning results, as suggested by Verbeek (2016). Before making any such conclusions on the educational value of VR, several long-term research studies on learning results must first be concluded.

Verbeek also remarks that, since many VR applications offer an experience to learn in an explorational way, measurements of learning results could be hampered. These applications are therefore aimed primarily at learning implicitly rather than explicitly, which in turn is more complicated to assess.

A study on the learning effects of VR when applied to a museum concluded that 'it will be difficult to get real data on the effectiveness of learning through VR, as long as the novelty of VR is as distracting as it currently is' (Moesgaard, Fiss, & Warming, 2015).

An important reason as to why we cannot expect research on short term towards learning results of VR in primary education is brought forward by Ott (2015). Both the Oculus Rift and the Gear VR possess an age-restriction of 13+. The HTC Vive and Google Cardboard do not provide any such indication, though their companies advise young children not to use the hardware, or to use it only under adult supervision.

Furthermore, it is important to note that the educational value of a lot or VR applications is limited. Chris Fowler remarks that pedagogical considerations are often absent when it comes to VR applications and -studies (2015). Seeing how many applications are being developed by a small team of developers, academics and education experts do not seem to have a big role to play in the development process. A popular app like *Titans of Space* (2016) succeeds in offering an impressive journey into the solar system. However, the information about planets is primarily presented in text on the screen of your virtual spaceship. This information, which could be educational to the user, is not integrated with the overall experience and therefore does not optimally use the benefits of VR. Creating effective, educational content for VR requires a combination of expertises, something that currently seems scarce.

With the above reasons in mind, it is safe to assume that it will take more time before any clear learning results from VR in primary education can be examined.

3.7 Possibilities for education

Currently, neither positive nor negative learning results of VR are known (and, as mentioned, it will take some time before these results will come into play). This, however, does not mean we cannot begin looking for the possibilities of VR for education. More so, we do not believe we should wait on these results before we start experimenting with (the use of) VR in education.

There appears to be a remarkable enthusiasm towards VR in education. Of the academic literature available, the majority seems positive towards VR, pointing out several educational experiments with motivated students that proved successful. We have also noticed a lot of enthusiasm in teaching practice. This enthusiastic attitude appears to primarily be caused by people's initial experiences with VR. The promise that with VR, anything imaginable can be created, also seems to be the source of inspiration and creativity for many, as this promise suggests the possibility to shape complete learning environments for students.

A much-remarked benefit of VR as an educational tool is the possibility to simulate situations which otherwise involve a number of risks. Surgeons practicing surgeries, pilots practicing flight movements and offshore-personnel practicing emergency situations are all examples of existing, specialistic applications. In this regard, VR seems rather similar to education as a whole: within the safe environment of a classroom, students practice their French conversations and make marketing plans, while debate clubs prepare students for discussions to be had in their business careers and engineers in-training are honing their skills by designing buildings.

In Kennisnet's publication on VR (2016), remarks are made about the benefits of making learning material vivid and clear. History class could be supplemented with 360º images of historically important sites, Geology class could offer a journey into a volcano and Biology class could provide immersive imagery of the deep sea, all without ever having to leave the classroom.

Kennisnet's publication also stresses the importance of creating a lesson around a VR experience. By asking questions, focusing attention on points of interest and evaluating properly, applications that are not educational in nature can nonetheless be used effectively to educate. *Google Expeditions* appears to have integrated these elements into the platform in an interesting way. Teachers are able to choose a lesson (or decide to make one themselves) in which they guide their students through different places, providing relevant information and asking questions in the process.

Alternatively, VR can be put to good use by having teachers and students make their own content. This also contributes to media savviness, as students become both consumers and creators. They could, for example, use a 360º camera to narrate a journalism story, or produce an assignment in the form of an environment through the use of platforms such as *Beloola*, *JanusVR* and *Minecraft*. Students training to become teachers could record their lessons with a 360º camera in order to later study the interaction(s) in their classroom.

The possible applications of VR in education are far greater than what we have so far discussed. During the many dozens of brainstorm-sessions we have had with various groups, new ideas for surprising applications came into being. VR is a new medium of which only a portion of its possibilities, regulations and limitations are currently known to us. We have sufficient grounds to keep experimenting with VR in education, which in turn might influence development of the medium itself. (de Lange, 2016).

3.8 Practical experience

For this study, employees of the NRO Kennisrotonde have conducted interviews with teachers Jasper Bloemsma (de Uitvinding, @JasperBloemsma) and Jeffrey Swerissen (Bosbergschool, @meester_Jeffrey).

Both teachers use Virtual Reality as part of their lessons. For example, a short clip normally shown on the interactive whiteboard is replaced by a VR experience (titled “Roman Pantheon Cardboard”) around the Pantheon. During a lesson about volcanoes, students can experience a helicopter-flight above an eruption through the use of 360º video “Expedition to the heart of an active volcano” on Youtube. The number of available VR-headsets and mobile devices are limited, thereby requiring students to take turns (each one being given three to five minutes to experience the VR application). Both Bloemsma and Swerissen deem the use of VR as valuable, since students react enthusiastically to the experiences. Students appear to enjoy the use of VR for educational purposes, though the initial level of enthusiasm seems to decrease over time.

Both teachers experience a number of challenges regarding their use of VR in class. First, they do not have sufficient VR-headsets and mobile devices for all students to experience it simultaneously. Second, there is hardly any VR-material available in Dutch which simultaneously connects well with both the content of lessons and the students themselves. Both teachers would be interested in seeing suitable material be developed specifically for use in primary education.

4 Augmented Reality

4.1 History and techniques

4.1.1 HMDs, smartphones and projectors

If the goal of VR is to allow users to experience a totally virtual reality, Augmented Reality concerns the enrichment or “expansion” of the “real”, physical world through the use of virtual elements. Although its objective differs, a majority of the technological challenges AR faces, overlaps with those found in VR. As such, a large part of early developments in the history of VR have been quite influential for AR as well.

In comparison to what VR experienced in the nineties, there has not been an apparent hype around AR. Instead, the field has developed itself towards specialistic applications for quite some time, e.g. valuable AR-HMDs used by fighter-pilots. The smartphones that became popular at the beginning of this century were the first to offer AR to a wider, more general audience. Smartphone- and screen-based AR has since become a considerable medium with popular applications such as *Layar*, *Pokémon Go*, *Aurasma* and *Google Skymap*.

One example of an AR application that many look forward to having, is a HMD so comfortable you could continuously wear it as if you were wearing glasses. With such a device, your environment would be enriched with digital, up-to-date information, completely integrated with (your observation of) your surroundings. Many consider such a concept as the ultimate interface to the digital world. Examples of well-know, recently released AR-HMDs are *Google Glass*, *Microsoft Hololens* and the *Meta 2*. All three devices differ in terms of comfortability, price and user experience. The *Google Glass* is light enough to be worn continuously, yet it uses quite a small screen. The *Hololens* is rather expensive (approx. € 3.000) and has a smaller image angle than what is advertised. While the *Meta 2*’s image angle is larger, this device requires to constantly be connected to a (powerful) PC. Important to note is that all suppliers seem to be years away from offering a product that can be considered ready to use by a larger, more general audience.

A different appearance of AR is in the form of projectors. For example, the game *Room Racers* (van Velthoven, 2012) uses physical objects in a room to create a racetrack that is projected on the floor. (Reed, et al., 2014) is describing an Another example is the “Augmented Reality sandbox”, where a height map is projected on a sandbox. By moving the sand around, the projected elevational information changes accordingly and virtual water flows towards newly-created spaces.

A hotchpotch of terms has come about in academic literature to describe different combinations of and interaction between virtual and real worlds: “Augmented Reality”, “Augmented Virtuality”, “Computer-mediated Reality”, “Hybrid Reality”, etc. The continuum between an entire real and virtual world has often being described with the collective term “Mixed Reality” (Figure 1). Recently, however, Microsoft's marketing department decided to interpret this term as a specific form of interaction wherein holograms are linked to elements of the real world, thus increasing the confusion around its definition.

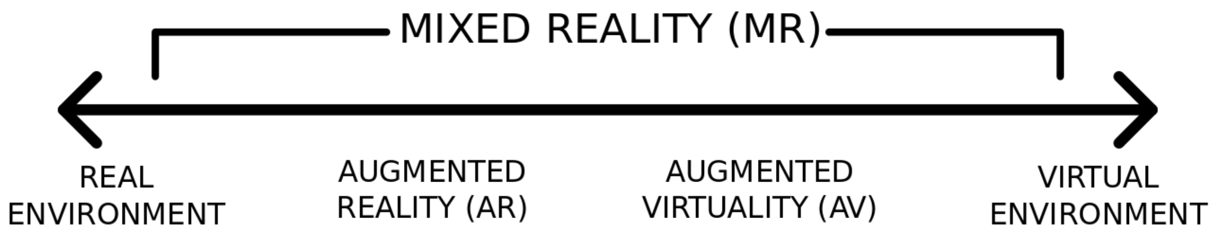

Figure 1

4.1.2 Recognition of objects

One of the biggest challenges AR applications face, is to connect virtual elements to elements in reality in a meaningful, valuable way. To achieve this, a computer must be able to recognize elements of the real world through the use of video-input and other sensors. This area of "feature detection" is the main interest of the field of Computer Vision. One of its goals is to enable computers to track objects in real-time, similarly to how humans are able to do this. As is often the case with the development of Artificial Intelligence, making computers mimic these human abilities is proving to be much more difficult than expected.

Nevertheless, we are seeing a lot of advancement in the development of "feature detection". Whereas AR required the use of QR-codes just a few years ago, pictures chosen by the user can nowadays be used as well. Computers are now able to recognize simple 3D objects, while live text-recognition is beginning to improve substantially. GPS-data can be used to present location-based information and depth sensor-devices like the Kinect provide applications with 3D-information about the environment. In 2016, Google's *Project Tango* was able to bring the latter functionality to smartphones, thus increasing the capabilities of AR considerably.

4.1.3 Interpretation of Augmented Reality

We have seen that AR possesses different appearances and interpretations. For this study, we thus made the decision to use a broad interpretation of AR that includes the different shapes and measurements between real-life and virtual elements. Because of this broad interpretation, we primarily focused on the differences in overall quality, immersiveness and the relation between virtual and real-life elements. When comparing AR to VR, this relation between virtual and real-life is what we deem to be the most important element of AR.

4.2 Search criteria & selection of literature studies

In order to find relevant articles about AR as an educational tool, we conducted a similar bibliographic searching procedure as the one conducted for VR. This bibliographic study was performed on November 15th 2016.

The decision was made to only use material published in or after 2010, as this year marks the arrival of Apple's iPhone, which made AR available for a much wider audience. Duplicate results were removed, as were results that we deemed too off-topic for this study.

Charts 4, 5 and 6 show a preliminary analysis of the metadata of these articles.

Chart 4	
Search criteria	**Number of results**

allintitle: augmented AND reality AND education	289
allintitle: augmented AND reality AND learning	564
allintitle: augmented AND reality AND primary	8
allintitle: augmented AND reality AND elementary	17
allintitle: augmented AND reality AND k-12	6
allintitle: augmented AND reality AND assessment	16

Chart 6	
Number of citations	**Number of articles**
0	418
>= 1	482
>= 11	94
>= 31	25
>= 101	6
285	1
Chart 5	
Year of publication	**Number of publications**
2016 >	102
2015	139
2014	150
2013	151
2012	107
2011	112
2010	61
Unknown	78
Total	900

4.3 Learning results

The hardware on which most AR applications run - smartphones and tablets - have had a high consumer adoption for a number of years now. These resources are also often available for use in primary education. Compared to VR, educational AR applications appear far more developed. Additionally, charts 3 and 6 show that the available literature on AR is more extensive than literature on VR. Literature on AR also appears to be more advanced, with several of its case studies reporting learning results and a number of its meta-studies (which are often cited) providing an overview of AR as an educational tool. For this study, we selected 26 research studies to examine in more detail.

In the process of studying learning results of AR, Elliot (2011) concludes that those using AR in conjunction with study books appear to perform better than those only using study books when learning scientific subjects. While Yilmaz (2015) reports positive learning results when comparing the sole use of AR with the sole use of study books, the quality of this study appears to be lacking. Zhu (2014) describes a meticulous, global analysis of 25 papers (selected from over 2500 papers) on the use of AR in medical education. Of these papers, 96% shows a positive attitude towards the usage of AR to improve medical education. Renner (2014) observed positive learning effects when using AR in chemistry education, though this positive effect decreases when using AR at classroom-level.

As is the case with VR, the number of academic studies on AR that show concrete learning results are limited. Furthermore, AR's possible forms of appearance and the areas of expertise in which it can make a difference are varied and diverse, thus making it too early to draw any significant conclusions on the effectiveness of AR as an educational tool.

4.4 Brain Learning and Augmented Reality

Similar to our approach with VR, we decided to look for any studies focused on possible connections between AR and Neuroscience. A search query (similar to the one we performed on VR) delivered 3 research studies, all of them lacking any relevant results.

In the aforementioned *De lerende mens*, neural functioning of a well-known effect is being discussed: humans appear to make associations between several pieces of information if these pieces come to them simultaneously. Neurally, this can be explained with a simplification of the theory of Donald Hebb: 'neurons that fire together, wire together'. This principle points out an important aspect of the educational value of AR: with the use of an AR HMD, information can be added to objects in an environment, projecting pieces of information simultaneously. While learning a language, for example, one could form stronger associations between an object and the corresponding word for it.

4.5 Possibilities for education

The overviews of available literature reveal both the possibilities and limitations of AR as an educational tool. Some studies essentially only provide a list of other studies on the subject, though others apply results to learning theories, identify challenges and discuss future research.

Wu (2013) stresses the fact that while AR is offering new learning possibilities, some of these already appear in other digital learning environments. Furthermore, AR brings forth several additional technological and pedagogical challenges. Proper use of AR can be complicated (especially for young children) and could result in cognitive overload. Consideration must also be given towards how AR apps are being applied to educational practice. Wu discusses that, as opposed to conventional education, wherein the teacher is a central figure, AR often places students in the center.

One possible form of AR is using it as a display for 3D objects. One such example would be *Construct3D* (Kaufmann, 2002), an application often referred to in meta-studies. This prototype uses an HMD to enable users to interact with three-dimensional, geometric figures. *Anatomy 4D*, a screen-based AR application by DAQRI, projects a human body on a (printed-out) marker. By moving the screen around this marker, students can study 3D models of the body. While both of these applications utilize AR to enable users to study 3D models, no actual relation between the real- and virtual world is present; the real world basically only functions as a background. As such, we could ask ourselves whether this should be considered "true" AR, or if VR might be more suitable to these situations.

Nevertheless, there are ways to properly utilize the meaningful relation between the virtual and the real. For example, AR applications could be used while on a school trip to a historical location or to produce relevant information and inform students when they arrive on significant locations (Yuen, 2011). Alternatively, expansive information could be added to the contents of a museum. This information could even be personalized, catering to the level of education and fields of interest of a specific student.

The rise of language recognition in the field of AR promises innovative, new ways to display context-sensitive information. Application *Big Bird's Words* helps children learn words by motivating them to search for simple words in their own home and scan these. In doing so, educational material is being placed within the context of their own living environment, resulting in a more meaningful learning experience.

A form of AR often used in classes is connecting digital information with (the contents of) study books. Educator Britt van Dort describes how she uses *Aurasma* to connect explanatory videos to pictures in a book, thus providing students the opportunity to re-check information whenever they feel the need to (Kennisnet, 2016).

As with VR, there are many more interesting AR applications that unfortunately could not be discussed in this study. At time of writing, proper AR HMDs still seem to be a distant future. Regardless, screen-based AR offers a lot of ways with which schools can experiment.

5 Bibliography

Ahn, H.-S. &.-M. (2015). Analysis on the Effects of the Augmented Reality-Based STEAM Program on Education. *Advanced Science and Technology Letters, 92*, 125-130.

Bower, M. e. (2014). Augmented Reality in education–cases, places and potentials. *Educational Media International, 51*(1), 1-15.

Chang, G. P. (2010). Applications of augmented reality systems in education. *Proceedings of Society for Information Technology & Teacher Education International Conference*, *1.* San Diego, CA.

Chang, Y.-J. e. (2011). Investigating students' perceived satisfaction, behavioral intention, and effectiveness of English learning using augmented reality. *IEEE International Conference on Multimedia and Expo.* IEEE.

Chen, Y.-L. (2016). The Effects of Virtual Reality Learning Environment on Student Cognitive and Linguistic Development. *The Asia-Pacific Education Researcher, 25*(4), 637 - 646.

Chen, Y.-L. J.-L.-C. (2014). EFL Learning Scenarios: Effectiveness of Using 3D Virtual Reality. *Society for Information Technology & Teacher Education International Conference.*

Cherenkova, N. (2013). Educational games within fully immersive 3D virtual reality environment and assessment of user's possible learning outcomes. University of Reading.

Chiang, T. H. (2015). The effects of 5E learning strategies by image-based augmented reality of mobile learning for elementary students. *International Journal of Mobile Learning and Organisation, 9*(4), 301-314.

de Lange, R. (2013, 5). Augmented Education. *ar[t] magazine*, 64-71.

de Lange, R. (2016). *SURF Trendrapport - Virtual Reality hoofdstuk.*

de Lange, R. (2016, 5). *The dangers of techno-pessimism in education*. Opgehaald van Virtual Reality Learning Lab: http://vrlearninglab.nl/dangers-techno-pessimism-education/

de Lange, R. (2016). *Virtual Reality for Science & Education 2016 - a review*. Opgehaald van Virtual Reality Learning Lab: http://vrlearninglab.nl/virtual-reality-education-2016-in-review/

Elliot, S. &. (2011). Improving Student Science Knowledge and Skills: A Study of the Impact of Augmented-Reality Animated Content on Student Learning. *Proceedings of Society for Information Technology & Teacher Education International Conference 2011* (pp. 2097-2105). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

Facer, K. (2011). *Learning Futures: Education, technology and social change.* New York, NY: Taylor & Francis.

Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy? *British journal of educational technology 46.2*, 412-422.

Freitas, R. &. (2008). SMART: a SysteM of Augmented Reality for Teaching 2 nd grade students. *Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-Volume 2* (pp. 27-30). Swindon, UK: British Computer Society.

Google. (2016). Google Expeditions.

Harzing, A. (2007). *Publish or Perish*. Opgehaald van http://www.harzing.com/pop.htm

Herson, B. (2016, November). Empathy Engines: How Virtual Reality Films May (or May Not) Revolutionize Education. *Comparative Education Review 60*(4), 853-862.

Hwang, G.-J. e. (2015). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments, 24*(8), 1895-1906.

Ibáñez, M.-B. e. (2016). Support for Augmented Reality Simulation Systems: The Effects of Scaffolding on Learning Outcomes and Behavior Patterns. *IEEE Transactions on Learning Technologies, 9*(1), 46-56.

Janak, M. e. (2016). Virtual Reality As an Effective Simulation Tool for OSH Education on Robotized Workplace. *The 3rd International Conference on Industrial Engineering and Applications*, *68.*

Johnson, M. (2007). *The Meaning of the Body.*

Jou, M., & Wang, J. (2013). Investigation of effects of virtual reality environments on learning performance of technical skills. *Computers in Human Behavior, 29*(2), 433-438.

Jowallah, R. B. (2016). Virtual Reality" the next frontier for K-12 Education: Responding to Future Innovations. *Florida Distance Learning Association.* Florida.

Kaufmann, H. (2002). Construct3D: an augmented reality application for mathematics and geometry education. *Proceedings of the tenth ACM international conference on Multimedia* (pp. 656-657). New York, NY: ACM.

Kennisnet. (2016). *Virtual Reality in het onderwijs.*

Kesim, M. &. (2012). Augmented reality in education: current technologies and the potential for education. *Procedia Social and Behavioral Sciences*, 297-302.

Kim, S. e. (2015). The Effectiveness of Visualization System for Virtual Reality Learning. *International Journal of u-and e-Service, Science and Technology*, 151-160.

Küçük, S. S. (2016). Learning anatomy via mobile augmented reality: effects on achievement and cognitive load. *Anatomical Sciences Education, 9*(5).

Lartigue, J. T. (2014). Promoting k-8 learning using oculus rift: Employing virtual reality to increase learning outcomes in elementary biology. *E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, *1.*

Lee, K. (2012). Augmented Reality in Education and Training. *TechTrends, 56*(2), 13-21.

Lin, C.-Y. e. (2016). The Effect of Literacy Learning via Mobile Augmented Reality for the Students with ADHD and Reading Disabilities. *Antona M., Stephanidis C. (eds) Universal Access in Human-Computer Interaction. Users and Context Diversity. UAHCI 2016. 9739.* Springer International Publishing.

Lin, H.-C. K.-C.-K. (2015). Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system. *Interactive Learning Environments, 23*(6), 799-810.

LLC, D. (n.d.). Titans of Space.

Merchant, Z., Goetz, E., & Cifuentes, L. (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.

Moesgaard, T., Fiss, J., & Warming, C. (2015). Implicit and Explicit Information Mediation in a Virtual Reality Museum Installation and its Effects on Retention and Learning Outcomes. *European Conference on Games Based Learning.* Academic Conferences International Limited.

Molka-Danielsen, J. e. (2015). Creating safe and effective learning environment for emergency management training using virtual reality. *Norsk konferanse for organisasjoners bruk av IT*, *23.*

Noh, K.-H. H.-K.-H. (2010). Effect of Augmented Reality Contents Based Instruction on Academic Achievement, Interest and Flow of Learning. *The Journal of the Korea Contents Association, 10*(2), 1-13.

Ott, M. &. (2015). A literature review on immersive virtual reality in education: state of the art and perspectives. *Conference proceedings of eLearning and Software for Education (eLSE) No. 01.* Universitatea Nationala de Aparare Carol I.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York, NY: Basic Books, Inc.

Parsons., T. D. (2013). Visuospatial processing and learning effects in virtual reality based mental rotation and navigational tasks. *International Conference on Engineering Psychology and Cognitive Ergonomics.* Springer Berlin Heidelberg.

Patzer, B. (2014). The Effects of Training Modality on Anatomy Learning Outcomes: Augmented Reality vs. Fiberglass Models of the Heart. *Proceedings: 10th Annual Symposium on Graduate*

Research and Scholarly Projects. Wichita, Ks: Wichita State University, (p. 141). Wichita: Wichita State University.

Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing, 18*(6), 1533-1543.

Reed, S., Kreylos, O., Hsi, O., Kellogg, L., Schladow, G., Yikilmaz, G., . . . Sato, E. (2014). Shaping Watersheds Exhibit: An Interactive, Augmented Reality Sandbox for Advancing Earth Science Education. *American Geophysical Union (AGU) Fall Meeting 2014.*

Renner, J. (2014). Does Augmented Reality Affect High School Students' Learning Outcomes in Chemistry. Grand Canyon University.

Ryu, J. e. (2016). The Effect of 3D Immersive Virtual Reality on Virtual Presence and Perceived Usefulness in Machining Center Learning for Hearing Impaired Learners. *한국교육공학회 학술대회발표자료집*, 16-17.

Schofield, D. (2012). Mass effect: A chemical engineering education application of virtual reality simulator technology. *Journal of Online Learning and Teaching 8.1, 63*.

Shewokis, P. A. (2015). Brain-in-the-Loop Learning Using fNIR and Simulated Virtual Reality Surgical Tasks: Hemodynamic and Behavioral Effects. *International Conference on Augmented Cognition.* Springer International Publishing.

Slijepcevic, N. (2013). *The effect of augmented reality treatment on learning, cognitive load, and spatial visualization abilities.* Kentucky: University of Kentucky.

Stefan, L. F. (2016). Evaluating a Mixed-Reality 3D Virtual Campus With Big Data and Learning Analytics: A transversal study. *Journal of e-Learning and Knowledge Society*.

Sutherland, I. E. (1964). Sketchpad-A Man-Machine Graphical Communication System. *Proceedings of the SHARE design automation workshop* (pp. 6-329). ACM.

Sytwu, T.-A. &.-H. (2016). An Investigation of the Effects of Individual Differences on Mobile-Based Augmented Reality English Vocabulary Learning. *Mobile Learning Design*, 387-410.

Ternier, S. S. (2010). *Mobile Augmented Reality voor het Onderwijs.* Surfnet & Kennisnet, Innovatieprogramma.

Thorsteinsson, G. (2013). Developing an Understanding of the Pedagogy of Using a Virtual Reality Learning Environment (VRLE) to Support Innovation Education. (L. Shavinina, Ed.) *The Routledge International Handbook of Innovation Education*, 456-470.

tom Dieck, M. C. (2016). Enhancing art gallery visitors' learning experience using wearable augmented reality: generic learning outcomes perspective. *Current Issues in Tourism*, 1-21.

Tsai, J.-P. Y.-C.-S. (2012). Investigating the effect of virtual reality application on teaching assistance for machine tools operation education. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM).*

van der Helden, J., & Bekkering, H. (2015). *De lerende mens.*

van Velthoven, L. (2012). Room Racers: Design and Evaluation of a Mixed Reality Game Prototype. *Master's thesis, Media Technology, Leiden University, the Netherlands*. Opgehaald van Media Technology MSc. website:

http://mediatechnology.leiden.edu/images/uploads/docs/vanvelthoven-room-racers-design-and-evaluation-of_a-mixed-reality-game-prototype-thesis.pdf

Verbeek, D. (2016). Virtual Reality in Education?! *Edulearn Conference Proceedings.* Barcelona.

Voshart, D. (2015, 1 31). *Architecture and VR: PT1 History of VR*. Retrieved 12 16, 2016, from YouTube: https://www.youtube.com/watch?v=tdAaU0CRHng

Willingham, D. T. (2012). *When can you trust the experts?*

Wu, H.-K. e. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*(62), 41-49.

Yilmaz, M. R. (2015). Effects of Augmented Reality Technology in Science Education on Students Achievements. *, Proceedings of International Academic Conferences*, (p. 615). Amsterdam.

Yuen, S. G. (2011). Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange*, 119-140.

Zap, N. &. (2016). Virtual and Augmented Reality as Cognitive Tools for Learning. *Proceedings of EdMedia: World Conference on Educational Media and Technology 2016*, (pp. 1340-1347).

Zhu, E. e. (2014). Augmented reality in healthcare education: an integrative review. *PeerJ, 2*.