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Selected Issues II
Major Information Systems

Benefits of Augmented Reality in Educational Environments

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Index of Abbreviations

AR	Augmented Reality[1]
AV	Augmented Virtuality[1]
VR	Virtual Reality[1]

[1] cf. 2.1

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1. Introduction

1.1 Problem Statement

Bridging the gap between virtual and real worlds, Augmented Reality (AR) provides new possibilities of teaching and learning which have been increasingly recognized by educational reaserchers.[2] Although AR is one of the most emerging technologies in education in these days,[3] the unique value of AR learning environments remains unclear.[4] In addition, there are different types of AR applications in educational environments which may differ regarding their benefits towards educational outcomes.[5] This leads to the problem that educators are possibly not aware of potential benefits of AR applications in comparison to conventional learning tools.

This work considers two main research questions: 1. Which benefits are provided by an AR application in comparison to conventional learning tools? 2. How do those benefits differ regarding the different types of AR applications in educational environments?

Although recent studies have investigated the use of AR in educational environments[6, 7] and a first approach to consolidate AR benefits in educational environments has been made,[8] more evidence on the educational values of AR is needed.[4] Unfortunately, we were not able to replicate the approach by Radu (2014) in order to search for additional benefits because of missing information towards the applied methodology. In addition this approach does not consider the different types of AR applications in educational environments.

An overview of the benefits of AR in educational environments regarding the different types of AR applications would help educators to decide whether the implementation of AR is reasonable in certain educational scenarios.

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2 cf. Wu et al. (2013), p. 41.

3 cf. Johnson et al. (2010), p. 21.

4 cf. Wu et al. (2013), p. 48.

5 cf. Yuen et al. (2011), pp. 126-130.

6 Wu et al. (2013).

7 Lee (2012).

8 Radu (2014).

1.2 Objectives

The main objective of this work is to identify benefits which can be provided by AR as a learning medium in educational environments in comparison to conventional learning tools. Besides, we want to find out how these benefits differ regarding the different types of AR in educational environments.
To fulfill these objectives, we conducted a systematic literature review to identify and analyze relevant publications. Additionally, we clustered relevant publications with regard to the applied type of AR on the basis of the 'Five Directions of AR in education' by Yuen et al. (2011).

1.3 Structure

The structure of this work is described in the following. The first chapter is called 'Introduction'. It is divided into the subchapters 'Problem Statement', 'Objectives' and 'Structure'. In this chapter we describe the reason why we decided to research for benefits of AR in educational environments. In addition, we point out the main objectives of our work.
In the second chapter, which is called 'Augmented Reality in Educational Environments' and is divided into the subchapters 'Definition of "Augmented Reality"' and 'Five Directions of Augmented Reality in Educational Environments' we initially introduce our definition of AR and point out its meaning in today's education. Afterwards, we present the 'Five Directions'[9] in which AR in educational environments can be categorized.
The third chapter is called 'Systematic Literature Review'. It contains the subchapters 'Data Collection' and 'Data Analysis' in which we describe our research approach.
In the fourth chapter, which is called 'Benefits of Augmented Reality in Educational Environments' and is divided into the subchapters 'Benefit Categorization' and 'Mapping of the Benefits to the "Five Directions"', we present the main findings of our systematic literature review. Initially, we present the benefits we found during our literature analysis and provide groups of related benefits. Afterwards, we regard the relationship between the different directions of AR in educational environments and the benefits we identified.

[9] cf. Yuen et al. (2011), pp. 126-130.

The fith chapter is called ‘Discussion’. In this chapter we discuss interesting aspects of our main findings before we mention the factors which limit our research.

In the sixth chapter, which is called ‘Conclusion’, we provide the conclusion of our research.

2. Augmented Reality in Educational Environments

2.1 Definition of "Augmented Reality"

Although the term ‘Augmented Reality’ was coined in 1990 by Tom Caudell, a former Boeing researcher, the concept of augmenting the real world with virtual data was initially used by a number of applications in the late 1960s and 1970s. Since the 1990s, AR was used by some large companies in purpose of visualization and training. Nowadays, the rising power of personal computers and mobile devices enable the concept of AR to be delivered to traditional educational environments such as schools and universities.[10]

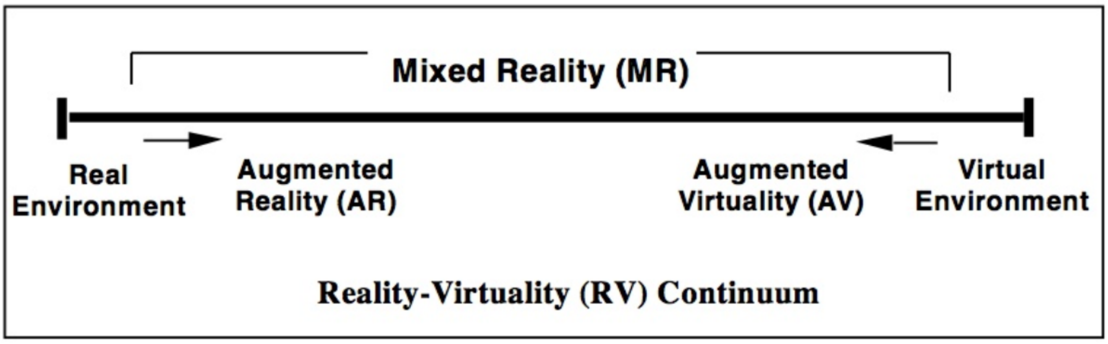

Fig. 2-1: Reality-Virtuality Continuum[11]

During the last years the term ‘Augmented Reality’ has been given different meanings by varying researchers.[12] Milgram et al. (1994) defined AR on the basis of the reality-virtuality continuum (Fig. 2-1) as "augmenting natural feedback to the operator with simulated cues".[11] The reality-virtuality continuum (Fig. 2-1) allows us to distinguish the concept of AR to related concepts such as Virtual Reality (VR) where "the participant observer is totally immersed in a completely synthetic world"[11] or Augmented Virtuality (AV) where "the the primary world being experienced is in fact [...] predominantly ’virtual’"[13] and augmented with information from the real world. In addition, Milgram et al. (1994) mention a more restricted definiton where AR is seen as "form of virtual

[10] cf. Johnson et al. (2010), p. 21.

[11] Milgram et al. (1994), p. 283.

[12] cf. Wu et al. (2013), p. 42.

[13] Milgram, Kishino (1994), p. 4.

reality where the participant's head-mounted display is transparent, allowing a clear view of the real world".[14] As suggested by educational researchers,[15] we reject the idea that the concept of AR is limited to any type of technology. Therefore, we broadly define AR referring to Klopfer, Squire (2008) as "a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information"[16] and regard it as a concept which is based on and realized by but conzeptualized beyond technology.

2.2 Five Directions of Augmented Reality in Educational Environments[17]

There are several different ways how the concept of AR can be implemented in educational environments.[17, 18] The Five Directions by Yuen et al. (2011) enable us to classify the AR applications we are investigating in our systematic literature review into five groups which are introduced in the following. This classification helps us to find out how the benefits of AR in educational environments differ dependent on the regarded type of AR application.

Discovery-based Learning

AR is often used in applications that enable discovery-based learning. Therefore, the user is provided with information about a real-world place while simultaneously regarding the object of interest. This type of application is often used in museums, in astronomical education or at historical places.

Objects Modelling

AR is also used in objects modeling applications. These applications allow students to receive immediate visual feedback of how a given item would look like in a different setting. Some applications also allow students to design virtual objects in order to investigate their physical properties or interactions between objects. This type of application is also

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14 Milgram et al. (1994), p. 283.

15 cf. Wu et al. (2013), p. 42.

16 Klopfer, Squire (2008), p. 205.

17 cf. Yuen et al. (2011), pp. 126-130.

18 cf. Lee (2012), pp. 14-18.

used in architectural education.

AR Books

AR books are books which offer students 3D presentations and interactive learning experiences through AR technology. The books are augmented with the help of technological devices such as special glasses. The first implementations of AR books show that this kind of medium is likely to appeal to digital native learners which makes it an appropriate educational medium even at the primary level.

Skills Training

The support of training individuals in specific tasks is described by the term ‘Skills Training’. Especially mechanical skills are likely to be supported by AR skills training applications. AR skills training applications are used for example in airplane maintenance, where each step of a repair is displayed, necessary tools are identified and textual instructions are included. Skills training applications are often realised with head-mounted displays.

AR Gaming

Video Games offer powerful new opportunities for educators which have been ignored for many years.[19] Nowadays, educators have recognized and often use the power of games and gamification in educational environments. AR technology enables the development of games which take place in the real world and are augmented with virtual information. AR games can give educators powerful new ways to show relationships and connections. In addition, they provide educators with highly interactive and visual forms of learning.

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[19] cf. Squire (2003), p. 2.

3. Systematic Literature Review

We applied a two-step research approach, whereby we first conducted a systematic literature review to identify relevant publications before analysing the identified publications for the coding of benefits and directions. After coding, we grouped all found benefits. This process is illustrated in Fig. 3-1 for data collection and in Fig. 3-2 for data analysis.

3.1 Data Collection

For the identification of papers addressing AR in educational environments, we applied a systematic online literature database search. We included databases which were specialised on more information systems centered papers, namely Institute of Electrical and Electronic Engineers (IEEE) Xplore Digital Library, ProQuest (ABI / INFORM), Association for Information Systems Electronic Library (AISel) and Association for Computing Machinery (ACM) Digital Library, as well as more general databases, namely EBSCO Host and ScienceDirect.

To find relevant papers, we searched within all databases on the following attributes: title, abstract and author supplied keywords. In our query we had three mandatory groups of keywords. Every article had to include the keyword ‘Augmented Reality’. Additionally, every article had to have at least one synonym for education and benefits. Namely we searched for ‘Educat*’, ‘Learn*’, ‘Teach*’, ‘College’ or ‘School’ as synonyms for education and ‘Benefi*’, ‘Advan*’, ‘Improv*’, ‘Enhanc*’, ‘Driver*’ or ‘Value*’ as synonyms for benefits. To deal with the limitations of some databases, we had to split our query and conduct multiple queries on the database and merge them together by hand.

This database query resulted in a total of 523 articles. Those results were checked against our include- and exclude-criteria, which are listed in Tab. 3-1. We limited the results to empirical works, because we wanted to gain insights into benefits of applied systems and benefits in real-world scenarios. Also, we focused only on positive effects to reduce the amount of data to process. Other aspects we excluded explicitly are non-human learning scenarios like machine learning and learning contexts with special requirements like students with disabilities. Both aspects were left out of our research because they require special attention.

This process of data collection was performed by all three authors and each article was

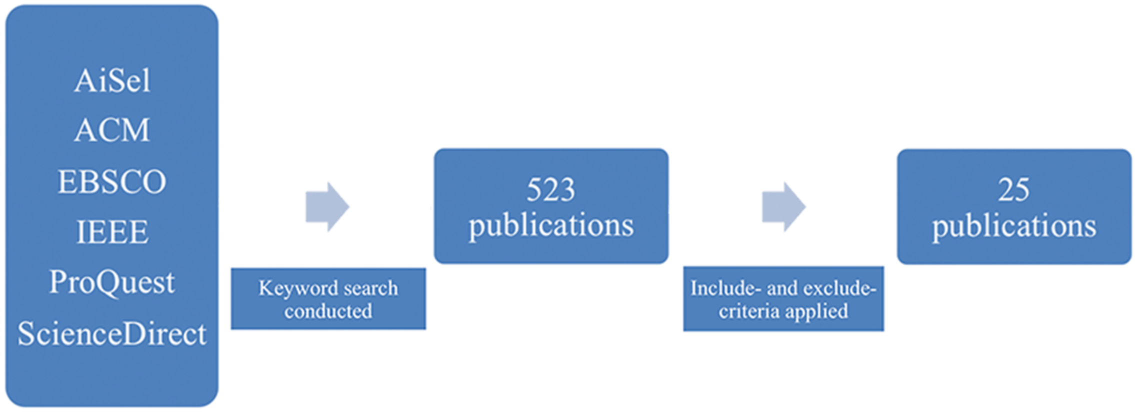

Fig. 3-1: Research Approach: Data Gathering

Include Criteria	**Exclude Criteria**
Empirical works	Theoretical works, grey literature, dissertations
A teaching problem is solved with the help of AR or a teaching concept is improved by AR	Untried or untested technologies, concepts without empirical evidence
Lists positive effects of AR applications in comparison to conventional learning tools	No control-group or control-scenario provided, no comparison to conventional learning tools
Human learning	Machine learning
English language	Other language
Peer-reviewed	Not peer-reviewed
Students without disabilities or special requirements	Students with disabilities or special requirements

Tab. 3-1: Include- and Exclude-Criteria

read by two of the authors. After merging our results, a total of 25 articles remained, all relevant articles were printed bold in the bibliography.

3.2 Data Analysis

During data analysis we clustered all found benefits into major groups and matched all found benefits to the directions of the articles in which they were mentioned. We will go into details regarding the benefits found and the clustering of them in chapter 4.1 and the mapping process will be highlighted in chapter 4.2.

Because of our orientation towards the five directions, we assigned preliminary directions

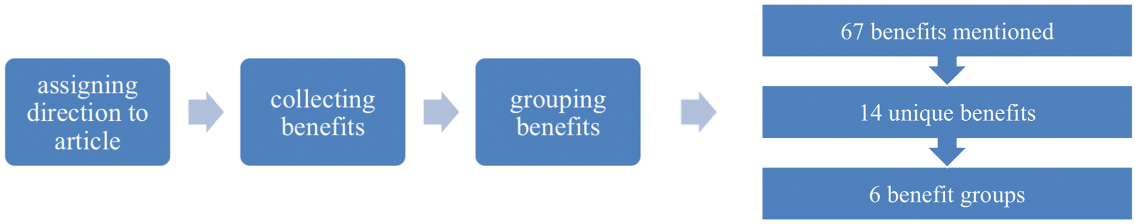

Fig. 3-2: Research Approach: Data Analysis

to all articles during data collection but revised our assignment in case of differences between the first and second coder. To measure our precision regarding the coding of the articles into directions, we utilised the inter-coder reliability score, proposed by Miles, Huberman (1994).[20] This score is calculated by dividing the number of agreements by the total number of agreements and disagreements. Our inter-coder reliability score is 0.64. We will interpret and discuss this score in chapter 5.

During assignment of directions we also collected all mentioned benefits and generalised similar benefits into a single one. Afterwards, those benefits were grouped into broader topic-related benefits. The process we applied is based on the process proposed by Jankowicz (2004).[21] The process proposed by Jankowicz (2004) helps by formalising the process of clustering.

A total of 99 quotes were collected and 67 benefits were mentioned, containing 14 unique benefits, which were clustered into six clusters. In the next chapter, we will introduce all found benefits and their major groups.

20 cf. Miles, Huberman (1994), p. 46.

21 cf. Jankowicz (2004), p. 149.

4. Benefits of Augmented Reality in Educational Environments

In this main-chapter we will present all benefits found. In the first sub-chapter we will present the benefits categorized in five different categories and afterwards we present the mapping of the benefits to the ‘Five Directions’.

4.1 Benefit Categorization

To improve clarity and to find semantically coherent groups, the benefits were clustered into a category in case they are logically related to the same subject, as you can see in the following.

4.1.1 State of Mind

In this subsection all benefits are presented which we grouped under the terms ‘State of Mind’. These benefits are related to the users state of mind while using the AR application. Some of these benefits can affect each other or are intuitive not clearly distinguished such as increased attention and increased concentration. Therefore some quotations could be interpreted as proof for another benefit, as you can see in the following. However the benefits differ in certain properties which we will point out in the respecting paragraphs. Especially we will pay attention to the benefits ‘increased attention’ and ‘increased concentration’ in this respect.

Increased Motivation

By increased motivation we mean that users have more eager and interest and are more engaged to deal with the new technology and thus also to deal with the teaching and learning content than by application of non-AR methods. With a fraction 21,74% of all benefits mentioned, ‘increased motivation’ is after ‘improved learning curve’ (26.87%) by far the most mentioned benefit, the third most are ‘Reduced Cost’ and ‘Improved Development of Spacial Abilities’ with fractions of 5,8%. This is shown by some quotations by Dünser et al. (2012), Iwata et al. (2011), Kamarainen et al. (2013), Liu et al. (2009), Martín-Gutíerrez et al. (2011), Martín-Gutíerrez et al. (2011), Tian et al. (2013), Redondo et al. (2013), Vate-U-Lan (2012) and Yen et al. (2013), who present this benefit literally, such as "[...] the AR-style game play successfully enhanced intrinsic motivation towards the self-learning process",[22] "Participants using the AR books appeared much more eager at the beginning of each session compared with the NAR group"[23] or "students have been satisfied and motivated by these new methodologies, in all cases".[24] Furthermore it is also shown by some implicit statements like "results showed that students were less bored and more in flow state when the AR-based application was used during the Magnet_2 stage"[25] or by findings such as the users "were more proactive"[26, 27] or the will to continue learning using the AR-Technology after class.[28] A more detailed description was found also in Iwata et al. (2011), where physical interaction is explicit identified as a driver to enhance emotional engagement.[29] Additionally this benefit was found in Li et al. (2011) and Hou et al. (2013).[30, 31]

Increased Attention

The benefit 'Increased Attention' is about the amount of attention the user pays to the technology and with this to the teaching and learning content. It is once mentioned literally by Vate-U-Lan (2012).[32] In the other two cases, we interpreted the quotations "felt it interesting [...] using the AR-guide system"[33] and "teachers noted that the smartphones [the AR-System] promoted interaction with the pond (of which the pupils should learn something about) and classmates"[34] as proof for increased attention. As said at the beginning of this chapter, such cases could be interpreted in other ways.

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22 Iwata et al. (2011), p. 113.

23 Dünser et al. (2012), p. 112.

24 Redondo et al. (2013), p. 60.

25 Ibáñez et al. (2014), p. 8.

26 Chang et al. (2014), p. 10.

27 cf. Zhang et al. (2014), p. 187.

28 Liu et al. (2009), p. 8.

29 cf. Iwata et al. (2011), p. 8.

30 cf. Li et al. (2011), p. 322.

31 cf. Hou et al. (2013), p. 448.

32 cf. Vate-U-Lan (2012), p. 894.

33 Chen, Wang (2008), p. 194.

34 Kamarainen et al. (2013), p. 552.

Increased Concentration

The difference between the benefits ‘increased attention’ and ‘increased concentration’ is just the fact, that we found it literally in the literature. We included it without any further interpretation or consideration to possible overlapping in the meaning of the terms. ‘Increased Concentration’ is about the amount of concentration while using AR applications. This benefit was also found for three times. Similar to the detailed description of Iwata et al. (2011) for increased motivation through AR application, "physical interaction induced deeper concentration [...]",[35] too. Yen et al. (2013) as well as Ibáñez et al. (2014) perceive an "higher [...] degree of concentration"[36] respectively a "higher level of concentration".[37]

Increased Satisfaction

‘Increased Satisfaction’ means that users experience higher satisfaction regarding the learning process or that users were more satisfied regarding what they have learned after learning with the AR application than with the conventional method. As an example of more satisfaction regarding the learning process, students have more fun running through a library an solve some tasks directed by an AR application than by a librarian.[38] Martín-Gutíerrez et al. (2013) says, that "the students were quite satisfied with the [AR-]tools used to learn".[39] A reverse statement therefor is that the frustration level is higher using the manual way.[40] Additionally this benefit is mentioned by Ibáñez et al. (2014) and Redondo et al. (2013), so in total five times.

4.1.2 Teaching Concepts

During our analysis we observed that two different teaching concepts were supported by AR applications. We clustered these concepts as ‘Student Centered Learning’ and ‘Collaborative Learning’ which we explain in the following.

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35 Iwata et al. (2011), p. 9.

36 Yen et al. (2013), p. 173.

37 Ibáñez et al. (2014), p. 11.

38 Chen, Tsai (2012), p. 649.

39 Martín-Gutíerrez et al. (2013), p. 6.

40 cf. Hou et al. (2013), p. 448.

Increased Student Centered Learning

Student centered learning is a teaching concept where conventional lectures are replaced by new active and self-paced learning programs. In student centered learning approaches, students are more self-responsible for their own progress in education and educators act as faciliators, who enable the students to learn independently and individualized.

Three studies report that AR enabled an increased student centered learning approach in the regarded learning environment. Vate-U-Lan (2012) recognizes that the regarded AR application enabled "functionality depended on [...] students' learning capability".[41] Similarly, Kamarainen et al. (2013) report that "these technologies provide ways of individualizing instruction in a group setting".[42] In addition, Kamarainen et al. (2013) state that "the technology supported independence" which "freed the teacher to act as a faciliator".[42] Furthermore, Liu et al. (2009) report that AR "improves the ability to explore and absorb new knowledge and solve problems"[43] which indicates that AR can support student-centered learning environments as students are enabled to explore knowledge and solve problems autonomously. These studies show, that AR can support a student centered learning approach by providing educators with new possibilites to individualize their lessons to students' capability and by enabling students to learn more independently from educators.

Improved Collaborative Learning

Three studies report that the regarded AR application improved collaborative learning, meaning that AR enabled new ways of communication and cooperation. Wang et al. (2012) regard their AR application as "effective environment for conducting collaborative inquiry learning activities".[44] Other authors join the observation of improved collaborative learning as they highlight "the opportunity for collaborative communication and problem-solving among students that arose from the augmented reality experience"[45] and

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[41] Vate-U-Lan (2012), p. 894.

[42] Kamarainen et al. (2013), p. 554.

[43] Liu et al. (2009), p. 173.

[44] Wang et al. (2012), p. 57.

[45] Kamarainen et al. (2013), p. 552.

the "facilitation effects of AR technology on collaborative learning effectiveness".[46]

4.1.3 Presentation

All benefits in the group ‘Presentation’ are related to the way in which content which should be learned or taught or objects which should support the learning process are visually presented to the user.

Increased Details

The benefit ‘Increased Details’ is mentioned once. In the context of urban design education the tested AR "has more detailing particular in the texture of models"[47] than using wood block models of objects for urban design learning, as it is the case in the traditional learning method.

Increased Information Accessibility

It is reported twice, that AR applications improves and eases the access to information regarding the teaching and learning content. In the context of an assembly task guided by an AR application instead of an conventional assembly manual, Hou et al. (2013) report that "[...] AR eases information retrieval by integrating the task of searching information and the task of the actual assembly".[48] Also Iwata et al. (2011) mention, that "superimposed information was nicely integrated and did not interfere with the learning process"[49] while learning a traditional Chinese board game.

Increased Interactivity

The benefit ‘Increased Interactivity’ could be seen as a precondition for other benefits presented in this paper, which it is, as you can see in the following and as noted in benefit ’Increased Motivation’. However, increased interactivity through the application of AR is a

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46 Li et al. (2011), p. 322.

47 Chen, Wang (2008), p. 17.

48 Hou et al. (2013), p. 447.

49 Iwata et al. (2011), p. 112.

fact which is not recognised by application of the corresponding conventional method[50, 51] and therefore specified as a single benefit. Dünser et al. (2012) state, that "tangible interaction using tools such as the magnet paddle and augmented nail with labeled poles [in the context of teaching physics] allow for a learning experience that combines real world objects with virtual content. Together this can contribute to a deeper understanding. Interactions in AR engage learners with the content, and allow for knowledge to be acquired through their own manipulation of content [...], as supported by constructivist learning theory [...]."

4.1.4 Learning Type

This subsection deals with benefits we clustered as 'Learning Type'. This group contains benefits which were linked to a specific type of learning, for instance creativity or a more theoretical learning approach like language education.
Therefore this group contains two sub-items: improved learning curve and increased creativity. While an improved learning curve is observable on skills based learning, such as spatial skills, or on fields which require a logical understanding, such as languages, increased creativity can be observed on less theoretical grounded areas, such as problem solving or arts.

Improved Learning Curve

An improved learning curve, meaning that students learn faster and easier with AR applications compared to non-AR applications, is the most often mentioned benefit of AR. A total of 26.87% of all benefits mentioned were related to an improved learning curve.
Liu (2009) reports that "tests taken by the experimental group [the AR application users] in all the learning activities were significantly better than those of the control group [the traditionally learning users]".[52] Similarly, Chang et al. (2014) state, that "[t]he AR-guided group had better learning effectiveness (as evidenced by their posttest scores), and it was found that most visitors believed the AR guide made it easier to digest information than

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50 cf. Dünser et al. (2012), p. 113.

51 cf. Ibáñez et al. (2014), p. 11.

52 Liu (2009), p. 525.

the audio guide due to the extra visual commentary that is provided"[53] as well as "[t]he learning performance of the AR-guided group was thus superior to that of the other two groups".[54] More authors join this observation like Kamarainen et al. (2013) ("[w]e witnessed significant learning gains"[55]), Ibáñez et al. (2014) ("it was found that students who used the AR application performed significantly better on knowledge"[56]), Li et al. (2011), Martín-Gutíerrez et al. (2011), Redondo et al. (2013), Liu et al. (2009) ("achieved significantly more learning improvement"[57]), Zhang et al. (2014), Yeo et al. (2011), Hou et al. (2013) ("[AR] shortens the learning curve",[58] "[the] learning curve of trainees significantly improved"[59]), Wilson et al. (2013) and Anderson et al. (2013) ("learning [results] increased by more than a factor of 2"[60]).

Increased Creativity

Increased creativity was mentioned three times (which makes 4,48% of all reported benefits). For instance, Liu et al. (2009) found that "it [AR] also improves student creativity and the ability to explore and absorb new knowledge and solve problems".[61] Vate-U-Lan (2012) reports, that the "AR 3D pop-up book has highlighted many benefits that include: [...] integration of a variety of learning skills such as [...] and creativity [...]".[62] Also, Chang et al. (2014) observes, that "[o]verall the visitors using the mobile AR-guide system during painting appreciation activities felt that it was an interesting, innovative, creative, and entertaining guide device".[63] To increase the interpretability of the impact of AR applications on creativity, more studies are needed.

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53 Chang et al. (2014), p. 193.

54 Chang et al. (2014), p. 190.

55 Kamarainen et al. (2013), p. 550.

56 Ibáñez et al. (2014), p. 12.

57 Liu et al. (2009), p. 173.

58 Hou et al. (2013), p. 450.

59 Hou et al. (2013), p. 451.

60 Anderson et al. (2013), p. 318.

61 Liu et al. (2009), p. 173.

62 Vate-U-Lan (2012), p. 894.

63 Chang et al. (2014), p. 194.

4.1.5 Content Understanding

The subsection 'Content Understanding' deals with benefits related to the understanding of the learning content by the user and with this the ability to keep the content in memory.

Improved Development of Spacial Abilities

The benefit of 'Improved Development of Spacial Abilities' is mentioned four times. Dünser et al. (2012) for instance says that their "results support the hypothesis, and suggest that Augmented Reality has some potential to be effective in aiding the learning of 3D concepts".[64] Literally and more detailed, the benefit was found in Martín-Gutíerrez et al. (2011) as they say that "the training of spatial ability based on Graphic Engineering contents and AR technology improves spatial abilities for those who perform them and consequently lower the numbers of students who drop out of the subject".[65] Additionally this benefit is mentioned by Martín-Gutíerrez et al. (2013) and Chen, Wang (2008).[66, 67]

Improved Memory

'Improved Memory' refers to the retention of what was learned during the application of the AR-method. Hou et al. (2013) state that "trainees with AR training could remember or recollect more assembly clues that were memorized in the former training task than those trained in the manual".[68] Furthermore it is not only about the mere memory, but also about how vivid the memory is. As Chang et al. (2014) say "[i]t [the AR application] facilitates the development of art appreciation by imprinting the knowledge of paintings on visitor's memories, supporting the coupling between the visitors, the guide system, and the artwork (Klopfer & Squire, 2008) by using AR technology, and helping visitors keep their memories of the artwork vivid".[69] Also Macchiarella et al. (2005) say that AR "lead[s] to an increased ability to retain long term memories".[70] This benefit is mentioned

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64 Dünser et al. (2012), p. 112.

65 Martín-Gutíerrez et al. (2011), p. 5.

66 cf. Martín-Gutíerrez et al. (2013), p. 4.

67 cf. Chen, Wang (2008), p. 5.

68 Hou et al. (2013), p. 450.

69 Chang et al. (2014), p. 193.

70 Macchiarella et al. (2005), p. 4.

three times in total.

4.1.6 Reduced Cost

Leblanc et al. (2010) and Martín-Gutíerrez et al. (2011) reported reduced costs in AR-scenarios compared to traditional learning in long term. Chen, Tsai (2012) highlights especially the low cost in executing manpower and moderate costs for designing and renewing of courses.[71] Andujar et al. (2011) join in this point, especially for virtual laboratories.[72] Andujar et al. (2011) add that AR-applications not only reduce direct costs, such as needed materials, but also time for preparing classes. While, at least at the time of this review, AR-technology is accompanied with high aquisition cost, this investment will most likely be paid off in the long term. Leblanc et al. (2010) report, that the one time acquisition cost were high (25.000 US-Dollar),[73] but the cost per class could be lowered by 93,34% (from 3.000 US-Dollar to 200 US-Dollar)[74] which will lead to an overall cost reduction.

71 cf. Chen, Tsai (2012), p. 640.

72 cf. Andujar et al. (2011), p. 492.

73 Leblanc et al. (2010), p. 253.

74 Leblanc et al. (2010), p. 253.

4.2 Mapping of the Benefits to the "Five Directions"

Following, we will present the mapping of the found benefits to the five directions. In Tab. 4-1 the mapping results are listed in detail.

As highlighted in 3.2, we followed the theoretical approach of clustering proposed by Jankowicz (2004).[75] First, we assigned articles to one of the Five Directions by Yuen et al. (2011).[76] The definitions by Yuen et al. (2011) state different aspects and characteristics for every direction, which we tried to match to the reviewed articles. After the assignment of a direction to each article, we counted the occurrences of each benefit found in the articles for each direction. Our results will be presented below.

4.2.1 Discovery-based Learning

We found eight articles (32.00% of all articles in our result set) which presented learning concepts that were discovery-based. Those articles had the most mentions of state of mind benefits, especially increased motivation. 47.00% of all increased motivation benefits were related to a discovery-based AR application. Also, an improved learning curve was mentioned. About one third of all improved learning curves were observed in Discovery-based Learning environments. Nine out of 14 benefits were reported for Discovery-based Learning applications (64.29%), which is the most diverse pool of benefits we found during our literature review. Reduced costs were reported in one article for Discovery-based Learning applications.

4.2.2 Objects Modelling

In our result set of 25 articles, we found five articles (20.00% of all articles reviewed), which dealt with an Objects Modelling approach for the presented AR application. Similar to Discovery-based Learning applications, Objects Modelling resulted in an increased motivation and satisfaction. We found about 26.67% of all mentions of increased motivation in an Objects Modelling context. Also, an improved learning curve was observed. About 22.22% of all mentions of an improved learning curve were in coherence with an Objects Modelling application. It is noticeable, that although Objects Modelling itself is

75 cf. Jankowicz (2004), p. 149.

76 cf. Yuen et al. (2011), pp. 127-130.

highly interactive, we did not find any references of an increased interactivity in classes which used AR than in classes which did not. None of the Objects Modelling applications mention presentation-linked benefits. Also, we found no reports of increased creativity linked to Objects Modelling , but spatial abilities were reported to be developed better. Five different benefits were found in Objects Modelling applications, which is about 35.71% of all reported unique benefits. Objects Modelling applications are reported to have reduced costs in comparison to non-AR learning tools.

4.2.3 AR Books

Two articles (which makes a total of 8.00%) were found which were based on an AR Books application. AR Books applications were the least found direction in the reviewed articles. AR Books applications are also connected to an increase in motivation, but not as much as Discovery-based Learning or Objects Modelling. AR Books seem to provide balanced benefits. Six of 14 benefits were reported in context of AR Books which makes about 42.86%. No reduced costs were reported for AR Books applications .

4.2.4 Skills Training

We found seven articles (28.00% of all articles) which presented a Skills Training AR application. 50.00% (seven out of 14) of all unique benefits were also mentioned in Skills Training applications. Skills Training applications have the most mentions of content understanding, especially in improved memory. It is furthermore worth noticing, that Skills Training applications have the same count of mentions for improved learning curves as Discovery-based Learning applications. Both have the highest count for improved learning curves. It was reported that Skills Training applications reduced the costs in comparison to traditional learning tools.

4.2.5 AR Gaming

AR Gaming was presented in three articles of our result set which accounts for 12.00%. AR Gaming has most benefits in the state of mind group. An improved learning curve as well as better accessible information were reported. Content understanding and teaching concepts, such as collaborative learning, were not explicitly improved in the reviewed cases. Reduced costs were reported for AR Gaming applications from one article.

		Discovery-based Learning	Objects Modelling	AR Books	Skills Training	AR Gaming	Sums
State of Mind	Increased Motivation	7	4	2	1	1	15
	Increased Attention	2	0	1	0	0	3
	Increased Concentration	2	0	0	0	1	3
	Increased Satisfaction	1	2	0	1	1	5
Teaching Concepts	Student Centered Learning	2	0	1	0	0	3
	Improved Collective Learning	1	2	0	0	0	3
Presentation	Increased Details	0	0	0	1	0	1
	Easy Accessible Information	0	0	0	1	1	2
	Interactivity	1	0	1	0	0	2
Learning Types	Improved Learning Curve	6	4	1	6	1	18
	Increased Creativity	2	0	1	0	0	3
Reduced Costs	Reduced Costs	0	1	0	1	0	2
Content Understanding	Development of Spatial Abilities	0	2	1	1	0	4
	Improved Memory	1	0	0	2	0	3

Tab. 4-1: Mapping of Benefits and Directions (25 articles, six benefit groups, 14 different benefits and five directions)

5. Discussion

In comparison to Radu (2014), our study has some similarities as well as some distinctions. Radu (2014) mentions ‘spatial abilities’, ‘long term memory’, ‘collaboration’ and ‘motivation’. We found these benefits as well and therefor inherited them. But in contrast to Radu (2014), we condensed ‘content understanding’, ‘language association’ and ’physical task performance’ into ‘improved learning curve’. Depending on the direction of the application, we are able to disaggregate our condensed ‘improved learning curve’ benefit into a more detailed benefit, i.e. a Skills Training application with an improved learning curve is equal to ‘physical task performance’. We have to mention, that we have chosen to define ‘Development of Spatial Abilities’ as another benefit and even in another group, as some applications lead to a new level of spatial abilities which might not have been achieved without AR or is at least extraordinary improvements in spatial abilities. Martín-Gutíerrez et al. (2013) states, that "[...] the students have a probability of over 95% of improving their levels of spatial ability when performing the proposed training. Besides this, results show there is no improvement in control group levels"[77] which indicates that spatial abilities were improved far more than usual.
A larger difference compared to Radu (2014) is, that we segmented attention into two subcategories, namely concentration and attention. While Radu (2014) states that AR applications might fail to improve student’s attention or lead to an unintended focus on the technology itself and not the topic,[78] we found articles that state the opposite. Kamarainen et al. (2013) states, that "[t]he teachers stated that they began this project with skepticism about whether the technology would overwhelm the experience, holding the students’ attention at the expense of their noticing the real environment. However, teachers and investigators found the opposite to be true. Students were captivated when a squirrel dropped a seed from a tree near the path and nearly hit a classmate; they called out excitedly when they observed a frog near the shore.",[79] and therefor we think, that the drawback mentioned by Radu (2014) might be related to system design. Furthermore our segmentation into attention and concentration is based on the findings by Kamarainen

77 Martín-Gutíerrez et al. (2013), p. 4.

78 cf. Radu (2014), p. 314.

79 Kamarainen et al. (2013), p. 554.

et al. (2013). Attention relates to only an increased awareness of the situation and a focus on the broader environment, while concentration refers to an increased awareness of the topic or subject and an high level of cognitive activity. Some benefits we found were not mentioned by Radu (2014), namely reduced costs, student-centered learning, creativity as well as all presentation-related benefits, like increased details, easy accessible information and interactivity.

Regarding increased creativity as one benefit of AR applications, we would not have thought of creativity as one benefit in advance. On the contrary, we would have assumed, that a linear learning tool as AR applications, which are only able to display information that someone added by hand and interact in ways which are predefined. Our findings conversely show that a linear learning tool as AR applications is able to support creative, non-linear learning. This finding also stresses, that AR is a very flexible tool, which can be used in many educational environments and settings and for very different purposes - if it is applied thoroughly. Hannafin, Land (1997) state, that although "[s]tudent-centered learning environments, with or without technology, will not be the system of choice for all types of learning",[80] "they [student-centered learning environments] represent alternative approaches for fundamentally different learning goals"[80] and therefor "[i]t is important to recognize, however, that viable alternatives to direct instruction methods exist, alternatives that reflect different assumptions and draw upon different research and theory bases than do traditional approaches"[80]. These statements tend us to believe, that student-centered learning, especially with AR as a tool, may be an important new movement for education.

Discovery-based Learning seems to be a very promising AR direction. As outlined in 4.2.1 it has benefits ranging from increased motivation, improved learning curve to reduced costs and supports student-centered learning, as supporting a Discovery-based Learning-approach, the student is the center of the learning process and the learning process is adjusted to the student's needs and preferences. We could imagine this to be the way students learn in future.

Our study is limited by a number of factors. Firstly, some of the regarded empirical

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80 Hannafin, Land (1997), p. 197.

studies are only informal investigations with a low number of participants. The significance of the ascertained benefits of AR applications may be unclear in these cases. In addition, for some of the regarded directions we did not find enough articles in order to make a point about the diversity of benefits in comparison to other directions. However, AR is one of the most emerging technologies in education and the fact that 15 out of 25 articles we regarded were published in 2012 or later shows that these limitations can be overcome in the future when more empirical evaluations of AR applications in educational environments will be published. Once enough articles have been published we would suggest to investigate every direction of AR in education separately with a decent amount of regarded articles in order to find out more about the diversity of benefits between directions.

Another factor which limits our study is revealed by the inter-code reliability of 0.64 regarding the classification of articles to a certain direction of AR. We think that this rather low value can be explained by the circumstance that some articles can not precisely be classified to a single direction, e.g. a discovery-based learning application which uses game elements. In addition, the definitions by Yuen et al. (2011) leave some room for interpretation which we tried to reduce during our systematic literature review.

While Radu (2014) states also (potential) negative aspects of AR in educational environments, we focused on benefits, although negative aspects might offset benefits.

Another aspect we left out are ‘special learners’: while handicapped people have (sometimes) special requirements, we focused on more general aspects of AR in educational environments.

6. Conclusion

Finally, we want to stress, that each AR application is in it's own way unique and therefor it is not always easy to generalise. Each application has to be implemented thoroughly to prevent drawbacks in user interaction or system failures in order to profit from benefits.
Additionally, we imagine that 'special learners', e.g. handicapped people, can derive different as well as additional benefits out of AR applications for learning purposes due to their special requirements to learning methods and the special characteristics of AR. The exploration of these benefits could be an objective for future research in the field of AR applications in educational environments. We found 14 different benefits of AR in our source literature out of which two benefits ('Improved Learning Curve' and 'Increased Motivation') each accounts for over 20% of all benefits mentioned. Hence, other benefits with much lower representation could be focused on in future work assessing AR applications in educational environments. Similarly, future research should focus on single directions of the Five Directions.
To draw a conclusion, AR is eligible to be used in educational environments and we found many applications which successfully used AR to improve learning, i.e. in language education, training of mechanical skills and spatial abilities training. Nevertheless, AR is no magic bullet to educational environments.

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