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Selected Issues II
Major Information Systems

Benefits of Augmented Reality in Educational Environments

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Köln, Juni 2014

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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.[1] Although AR is one of the most emerging technologies in education in these days,[2] the unique value of AR learning environments remains unclear.[3] In addition, there are different types of AR applications in educational environments which may differ regarding their benefits towards educational outcomes.[4] This leads to the problem that teachers and professors 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[5, 6] and a first approach to consolidate AR benefits in educational environments has been made,[7] more evidence on the educational values of AR is needed. 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 teachers and professors to decide whether the implementation of AR is reasonable in certain educational scenarios.

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

2 cf. Johnson et al. (2010).

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

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

5 Wu et al. (2013).

6 Lee (2012).

7 cf. 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 'Definitions 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'[8] 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.

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[8] cf. Yuen et al. (2011).

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 by Tom Caudell, a former Boeing researcher, in 1990, 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. Nowerdays, 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.[9]

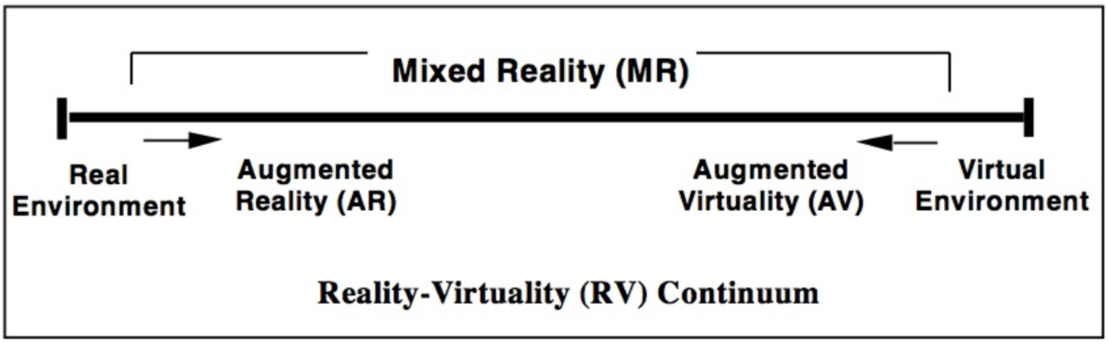

Fig. 2-1: Reality-Virtuality Continuum

During the last years the term 'Augmented Reality' has been given different meanings by varying researchers.[10] Milgram, Takemura, 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"[12] 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, Takemura, et al. (1994) mention a more restricted definiton where AR is seen

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

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

11 Milgram, Takemura, et al. (1994), p. 283.

12 Milgram, Takemura, et al. (1994), p. 283.

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

as "form of virtual 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

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

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

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

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 with on the following attributes: title, abstract and author supplied keywords. Within these keywords we had three mandatory groups of keywords. Every article had to include the keyword "AR ". Additionally, every article needed 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 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 ourselves and each article was read by two of the authors. After merging our results, a total of 25 articles remained.

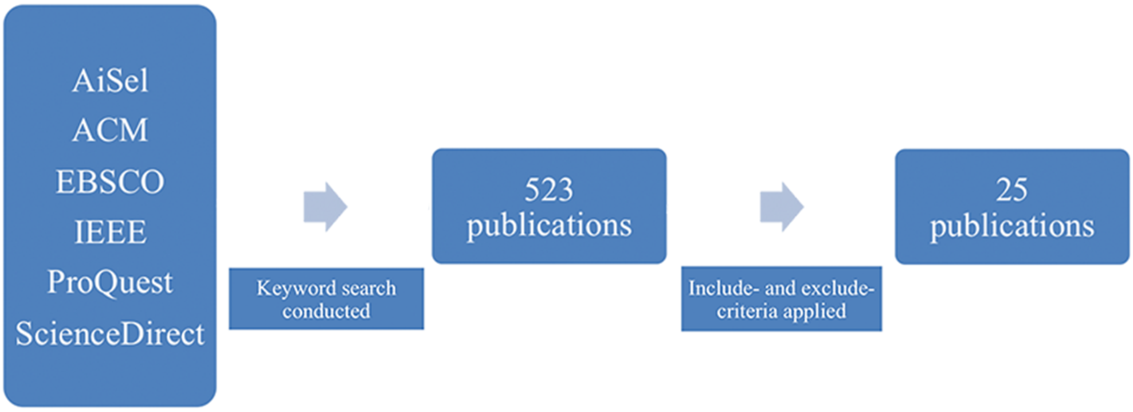

Fig. 3-1: Research Approach: Data Gathering

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

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

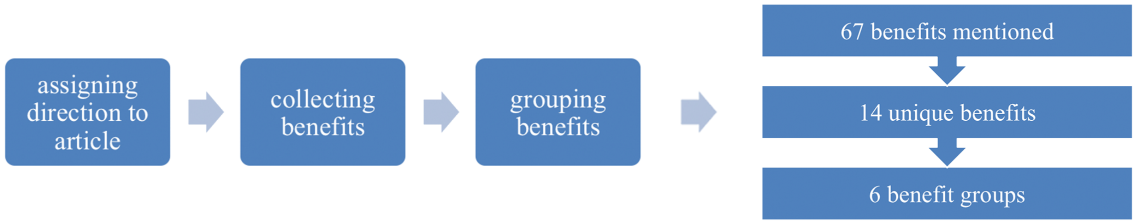

Fig. 3-2: Research Approach: Data Analysis

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).[17] 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).[18] The process proposed by Jankowicz (2004) helps by formalising the process of clustering.

A total of 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.

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

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

4. Benefits of Augmented Reality in Educational Environments

4.1 Benefit Categorization

4.1.1 State of Mind

Increased Motivation

Increased Attention

Increased Concentration

Increased Satisfaction

4.1.2 Teaching Concepts

Increased Student Centered Learning

Improved Collaborative Learning

4.1.3 Presentation

Increased Details

Increased Information Accessibility

Increased Interactivity

4.1.4 Learning Type

This subsection deals with benefits we clustered as 'Learning Type'. This group contains benefits which could be linked to a specific type of learning, for instance creativity or a more theoretical learning approach like language education.
Therefor this group contains two subitems: 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]".[19] Similarly, Chang et al. (2014) states, 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 the audio guide due to the extra visual commentary that is provided"[20] as well as "[t]he learning performance of the AR-guided group was thus superior to that of the other two groups".[21] More authors join this observation like Kamarainen et al. (2013) ("[w]e witnessed significant learning gains"[22]), Ibáñez et al. (2014) ("it was found that students who used the AR application performed significantly better on knowledge than those who were taught using the web- based application"[23]), Li et al. (2011), Martín-Gutíerrez et al. (2011), Redondo et al. (2013), Liu et al. (2009) ("achieved significantly more learn-

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19 Liu (2009), p. 525.

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

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

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

23 Ibáñez et al. (2014), p. 12.

ing improvement"[24]), Zhang et al. (2014), Yeo et al. (2011), Hou et al. (2013) ("shortens the learning curve",[25] "learning curve of trainees significantly improved"[26]), Wilson et al. (2013) and Anderson et al. (2013) ("learning increased by more than a factor of 2"[27]).

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 also improves student creativity and the ability to explore and absorb new knowledge and solve problems".[28] 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 [...]".[29] 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".[30] To increase the interpretability of the impact of AR applications on creativity, more studies are needed.

4.1.5 Content Understanding

Improved Development of Spacial Abilities

Improved Memory

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

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

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

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

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

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

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

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

especially the low cost in executing manpower and moderate costs for designing and renewing of courses.[31] Andujar et al. (2011) joins in this point, especially for virtual laboratories.[32] 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, but this investment most likely paid of in the long term. Leblanc et al. (2010) report, that the one time acquisition cost were quite high (25.000 US-Dollar),[33] but the cost per class could be lowered by 93,34% (from 3.000 US-Dollar to 200 US-Dollar)[34] which will lead to cost reduction.

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[31] cf. Chen, Tsai (2012), p. 640.

[32] cf. Andujar et al. (2011), p. 492.

[33] Leblanc et al. (2010), p. 253.

[34] 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 **??** the mapping results are listed in detail.

As highlighted in 3.2, we followed the theoretical approach of clustering proposed by Jankowicz (2004). First, we assigned articles to one of the Five Directions by Yuen et al. (2011). 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) whose presented learning concepts were Discovery-based. Those articles had the most mentions of state of mind benefits, especially increased motivation. 47% 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 (about 64.29%), which is the most diverse pool of benefits we found during our literature review. Reduced costs were reported from 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 coherence with an Objects Modelling application. It is noticeable, that although Objects Modelling itself is 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 in the 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
	Sums	12	6	3	2	3	
Teaching Concepts	Student Centered Learning	2	0	1	0	0	3
	Improved Collective Learning	1	2	0	0	0	3
	Sums	3	2	1	0	0	
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
	Sums	1	0	1	2	1	
Learning Types	Improved Learning Curve	6	4	1	6	1	18
	Increased Creativity	2	0	1	0	0	3
	Sums	8	4	2	6	1	
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
	Sums	1	2	1	3	0	

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

5. Discussion

6. Conclusion

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