# Theories, Design Elements and Measures used in AR for Teaching and Learning: Insights from a Literature Review

*Abstract*— **Education is one of the most promising application areas for Augmented Reality (AR). Many recent studies report positive effects when implementing AR technology in an educational setup. Based on a systematic literature review on theoretical and empirical foundations of AR for teaching and learning, we identified measures of learning performance currently used in research. Most studies measure learning performance in a subjective, self-reported way, e.g., through measures like perceived learning or perceived usefulness. Only few studies are grounded in learning theories, addressed measures and the relation between the design used for AR learning and their measures for success, useful to assess learning effects derived from learning theory and including AR in educational setups. Our findings contribute to the science of AR teaching and learning.**

***Keywords-augmented reality; learning theory; learning performance; learning measurement, design elements;***

## I. INTRODUCTION

Augmented Reality (AR) technologies enable to dynamically project digital information on physical objects in a real-world environment [37]. Education is one of the most promising application areas for AR. Recent advancements in mobile computing made the use of AR affordable for the broad public. Besides tablets and smartphones, the fuse of wearable AR displays (e.g., Google Glasses) and head-mounted displays (e.g., Microsoft Hololens) is an attractive way to create appealing learning experiences in education. Consequently, there is an increasing number of studies examining the use of AR in education [38]. Especially in terms of empirical studies, most research focus on user experience and learning performance. However, there is still a lack of knowledge about how the design of AR learning apps can be theoretically grounded in learning theories and subsequently empirically evaluated in terms of learning performance.

AR research has been documented in manifold ways and on a broad base. A variety of studies examined the evolution of fundamental technologies, investigated affordances of AR, compared student learning with and without AR, and reported on the opportunities and challenges of AR in education as well as its applications in industry [38, 39, 40, 41, 42]. AR supports to emphasize learner's roles and constructs a flexible and interactive learning environment, like in game-based learning and collaborative learning [43]. Consequently, the learning design is less influenced by learning theories, thus the learning experience is getting more and more into foreground [44, 45].

The New Media Consortium (MNC) provides a yearly outlook on technology trends in teaching and learning, and on advancements of AR in education in their Horizon Report [46]. In their latest report, they highlighted the importance of measuring learning performance and the acquisition of skills and competencies, as well as creativity and critical thinking [47]. To address this point, we conducted a systematic literature review. We searched for articles that document empirical studies of AR in education grounded in learning theories. We then identified the measures used for assessing learning success and their relation to AR design elements.

The remainder of this paper is structured as follows: We first present the method used for our literature search and provide theoretical background on learning theories. As our study was motivated by the interest of finding design parameters that are derived from learning theories, we then outline the selection and analysis processes we applied to translate our findings into a measurement framework for effective AR-based instructional design. After discussing our results, we conclude with a brief summary and directions for future research.

## II. LITERATURE SEARCH

In our systematic literature review, which was based on a database-driven literature search, we followed the process for systematic reviews by Gough et al. [48] consisting of four stages with four key activities: (1) propose a research question, (2) ascertain and qualify relevant research, (3) critically evaluate research articles using a systematic and comprehensible process, and (4) perform a conclusive analysis, provide a claim, evidence and reasoning section.

We aimed at finding research articles that document empirical studies in which AR was used for supporting teaching and learning. We were additionally interested in articles which are grounded in learning theories. Therefore, we defined four research questions: (RQ1) Which learning theories are used for designing AR apps for learning, teaching, and education? (RQ2) Which design elements are used to implement a particular learning theory into an AR app? (RQ3) How is the learning effect measured? (RQ4) Is the measured effect actually caused be the use of AR?

### A. *Search strategy*

We used the search term "augmented reality" AND "theory" AND ("learn* OR teach* OR educat*") in our EBSCO database-driven literature search between May and November 2017 and limited the search to peer-reviewed scientific articles available in English. This search strategy produced 291 initial results. After removing duplicates and erroneous entries, like articles still not in English language or that are not peer reviewed (although indicated in the meta data), 184 sources remained.

### B. *Article selection*

Continuing the selection process, we browsed through the theoretical and empirical sections of the articles. We excluded sources which were not providing any information about how learning theories were applied or not showing evidence for the design or use of AR technology. This reduced the list of articles to 52 articles. In a last screening step, we excluded articles that did not evaluate the effect of AR on learning, which left us with a final list of 36 relevant articles.

## III. Data Analysis And Findings

In our data analysis we aimed for a thorough and unbiased interpretation of the primary sources by applying a systematic synthesis method supporting this process [49]. Following a concept-centric approach [50], we evaluated the sources primarily on the basis of the used learning theories. Furthermore, we extracted features which support the construction of a measurement framework for effective AR-based instructional application design.

### *A. Learning theories used in AR for teaching and learning*

To structure and categorize the learning theories, we used the desk reference for learning theories, which is based on a knowledge collection from sixteen renowned scholars [51]. They determine that learning theories can be presented from a cognitive, behavioral or constructivist perspective, covering social aspects in learning environments, and constituting the cognitive, social and emotional dimension of learning.

We found two articles referring to behaviorist learning theories, namely stimulus-response pairs theory and selective reinforcement theory [17, 25]. The basic ideas behind the learning paradigm of behaviorism is to control and modify a learner's behavior by the acquisition of basic facts and skills [51]. Skinner [52] highlights behavior as the basic element of learning from a psychological perspective. Additionally, he argues that learning theories impede the empirical research on behavior theory. Following the idea of radical behaviorism is rather an experimental analysis than a theory [52]. Even more restrictive, Jarvis [51] rejects the idea of behavior as a driving force for human learning because of the ignorance and absence of meaning in learning.

Cognitivism is a learning paradigm that sees the mind as an information processor and focuses on internal cognitive structures to understand how information is received, organized, stored, and retrieved in the brain. Viewed from a pedagogical perspective, the processing and transmission of information can be executed through communication, explanation, recombination, contrast, inference, and problem solving in order to acquire external, existing knowledge [51; 53; 54; 55]. Cognitivism pretty much relates to the internal processes of information handling and storing.

In our literature analysis, three theories relating to cognitivism were identified, the cognitive theory of multimedia learning (CTML) proposed by Mayer [56], and the grounded cognition theory and embodied cognitive dissonance theory [24]. In CTML, Mayer presents three views of multimedia learning. The delivery-media view refers on the presentation of learning content using two or more devices for delivery. The presentation-modes view focuses on the presentation of material using two or more presentation modes. Finally, the sensory-modality view posits that two or more sensory systems in the learner are involved. On this basis, he proposes twelve principles of multimedia design which are meant to support multimedia learning [56].

Not all of those principles are fully applicable for AR learning, as shown by the studies implementing CTML in their AR learning applications [7, 8, 19, 13, 18, 26, 35]. While seven (19%) research articles are referring to Mayer's CTML, one study references the embodied cognitive dissonance theory and the grounded cognition theory. In the embodied cognitive dissonance theory Keebler et al. proposes that learning takes place using a multimodal link between perception and action by coupling the environment and the brain [24]. To understand embodied and grounded cognition theory, understanding a number of theories is relevant. In short, they reveal that sensory information is tied to its perceptual modality and influenced by the body and its movement. Additionally, one study implemented the principles of guided and open enquiry derived from the enquiry-based learning theory [57], which enables students to learn and practice a particular content in different ways, thereby also follow Mayer's CTML principles.

Constructivism is a learning paradigm that focuses on the processes by which learners build their own mental structures when interacting with an environment [58; 51]. Following a task-oriented pedagogical view, constructivism equates learning with creating meaning from experience, where learning is more meaningful to students when they are able to interact with a problem or concept. Constructivist learning theories emphasize the need to actively engage students in problem solving and motivate them through meaningful contexts. Constructivism utilizes interactive teaching strategies to create meaningful contexts that help students to construct knowledge based on their own experiences. Learning tasks are implemented by using high-order thinking skills and transferring knowledge into new situations, as done, for example, in simulated worlds, role-plays, debating, cooperative learning, and self-directed task-based learning [51; 59; 60].

About 28 (78%) articles were related to constructivist learning theories. In this group, we identified articles referring to situated learning, game-based learning and simulations, experiential learning, variation, transformative learning, collaborative learning, and meaningful learning. We added situated learning to the group of constructivism, which does not align with the categorization done in other studies. I.e. Dunleavy & Dede state in their review that situated learning is an extension of other learning theories, they categorized situated learning as a learning theory separated from other constructivist learning theories [61]. We agree, that each learning theory has the ability to extend other learning theories. We understand that learning based on constructivist theory relies on constructed processes which support the learning experience. Consequently, we allocated such theories to constructivist learning theory.

To summarize, we found the stimulus response pairs theory and the selective reinforcement theory in regards to behaviorism. In cognitivism, CTML, embodied cognitive dissonance theory, grounded cognition theory and enquiry-based learning theory are mentioned. The large group of constructivism included theories like simulation, variation, and situated, Game-based, experiential, transformative, meaningful and collaborative learning theory.

### *B. Design elements used in AR for teaching and learning*

Most studies which relate to cognitivist learning theories implemented design elements derived from the CTML in their applications [7, 8, 13, 24, 26, 35]. We found a variety of implemented design elements connected to constructivist learning theories in our literature review and categorized them according their related special activities (e.g., interactivity, communication, collaboration, participation). One goal for active involvement of students in learning is, to create an engaging learning experience, which describes the core mission of constructivism in education [20].

We also found that some research implemented elements from more than one learning theory [4, 5, 6, 8, 9, 10, 11, 13, 14, 15, 16, 20, 26, 28, 29, 30, 32]. Some studies used design elements like audio and pictorial information, superimposing information next to the real object and in real-time, highlighting hot-spots of information, etc. for imparting content, which follows the CTML principles. Additionally, they use special design elements derived from constructivist learning to create an active learning experience, like elements known from games or simulations (e.g., leaderboards, missions, communication, collaboration). In our literature analysis, we could identify articles that describe design elements implemented in their experimental setup but do not demonstrate the connection to their applied learning theory. We found in other studies the same design elements related to a different learning theory.

### *C. Learning theories and their performance measures used in AR for teaching and learning*

Besides socio-demographic measures (e.g., age, gender), we extracted measures which relate to the actual learning success and are grounded in learning theories. Many studies measured the effect of AR through experimental pre- and post-test designs in which the number of correctly memorized information before and after the intervention was compared [1, 5, 7, 10, 18, 19, 20, 32, 33, 34]. Such measures relate to the cognitivist view of learning. Others measured the number of trials performed [19, 24, 35] or time-related aspects (e.g., study time, response time) [18, 19, 24, 28, 35], or the number of attempts in a given timeframe [19, 24, 26] in relation to constructivist theory. The majority of studies included a survey to analyze the effect of learning in a qualitative (i.e. using open questions) or quantitative (i.e. using questions/statements in combination with Likert scales) way. The central measures applied in AR education research is perceived usefulness and perceived learning.

## IV. TOWARDS A FRAMEWORK FOR THEORIES, DESIGN ELEMENTS AND MEASURES IN AR LEARNING

We found only few studies analyzing benefits of using AR in education in detail. Especially papers related to the CTML offer explanations about single design elements (i.e. multimedia, space, time) effecting the overall learning achievement or addressing single performance measures.

Additionally, to create an impressive learning experience, AR has the ability to focusing learner's attention on key learning objectives, using image-based AR and location-based AR. When implementing mobility aspects (i.e. map information loaded onto mobile device), providing specification information (i.e. compass, G-sensor, angle and elevation, GPS) and elements following the accuracy principle (i.e. geometry, projection, proportion), the learning activity motivates students to interact with the learning environment and engage student interaction beyond themselves. Displaying information in real-time, using 3 D objects and applying knowledge and activities in real settings are key elements to fosters student's motivation and engagement in AR learning activities.

To answer the stated research questions, we summarized the findings from our literature review in a conceptual framework for measuring learning performance, applicable for the design of AR learning applications. Figure 1 shows the details from the framework.

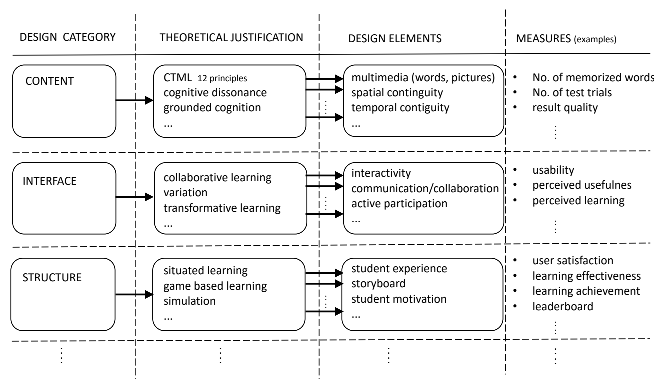


Figure 1. Framework for theories, design elements and measures.

We focus on the implementation of learning theories in specific design categories, following the ideas of Parhizkar et al. [13]. Possible design categories are content, interface and structure, but we would like to emphasize that the framework is not complete yet and allows to accommodate further design categories, theoretical justifications, design elements, and measures.

Applying the framework for AR learning application design will have as result tangible design and measurement statements. Such statements would follow the structure of referring to a particular design category, with reference to a theoretical justification like a specific learning theory and implementing specific design elements which will be evaluated by specific performance measures. The following example taken from our literature search illustrates how to apply the framework: "Sommerauer et al. [7] refer to five CTML principles (multimedia, spatial / temporal contiguity, modality, signaling principle) when implementing an AR learning app in a math exhibition. To provide specific information they superimpose videos demonstrating tangible mathematical phenomena. They measured the number of correct answers related to the provided information given by participants before and after using the app."

## V. Conclusion and Discussion

With our research we aimed to answer four research questions. Therefore, we analyzed learning theories used in research on AR for education. We identified the constructivist theory as the major class of theories that researchers refer to. Especially in terms of designing learning as learning experience, constructivist theory supports the construction of task-orientation which forces students to be actively involved in the learning activity. We understand theories like situated-, game-based-, experiental-, transformative-, collaborative-, meaningful learning or simulations as subcategories of constructivist learning. We could identify Mayer's 12 principles for effective multimedia learning (CTML) as effective for application design. Finally, it seems that most AR researchers are following the perspective of rejecting behaviorism as driving force for human learning because of the ignorance and absence of meaning in learning [51]. We could not identify a single research implementing behaviorist theory for performance measuring in AR learning, but we found two articles referring to behaviorism in their theory section.

What we found additionally is, that most researchers implement design elements as good as possible but did not aim to measure the influence of a particular elements, i.e. by modification and observing the change effects in their study. In consequence, the effect of AR in these studies necessarily did not rely on their used design or on any variable they controlled in the experiment. Besides, we found in nearly every single study the measurement of perceived usefulness for AR in education, mostly ascertained by using a survey or questionnaire after the learning session.

Latest since the publication of Billinghurst's compendium [40] it is conceivably that AR research is documented in a manifold way on a broad base. However, in our literature review we found less studies incorporating AR in learning that relies on learning theory and analyzing learning effects in a quantitative way, which would be usable for education especially for individual and organizational knowledge management support. Moreover, we systematically worked through other related literature reviews and could not find any evidence towards this research direction [38; 39; 40; 41; 42]. Our proposed performance measurement principles support the future development of AR applications in a conceptual and novel way, and is applicable in any learning environment.

Less papers are reporting negative effects [35] or no positive effect [2] when using AR in learning applications, except in the particular case of cognitive overload [8, 28, 29; 51]. Some research articles investigating several aspects of learning, but could not demonstrate a significant positive effect on single measures and identified an overall positive effect [3, 10, 25, 35]. However, developers of AR learning applications could learn also from negative research experiences, thus we would appreciate seeing more research results showing both, positive and negative effects.

Our study is not free of limitations. Since we used a strict approach towards applied learning theories in our literature review and concerning findings we were looking in detail for analysis. Knowing that we probably will miss articles that would also fit into our search profile, we attempted to compensate this aspect when including related literature reviews for our argumentation.

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