Beyond observation and interaction: Augmented Reality through the lens of constructivism and constructionism

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In recent years, Augmented Reality (AR) technology and the potential it offers for learning has increasingly moved into the focus of educational research. From a theoretical point of view, the use of Augmented Reality by implementing computer-based elements and models in the real environment not only offers the possibility to extend conventional learning settings, but also to create new, previously unthinkable learning opportunities. Previous research has outlined the potential of AR technologies in different learning contexts (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014; Cai, Liu, Yang, & Liang, 2019; Cheng & Tsai, 2016; Ibáñez & Delgado-Kloos, 2018; Lai, Chen, & Lee, 2019; Radu, 2014). These early examples have suggested that augmented reality has the potential to support learning interventions designed from a diversity of theoretical perspectives, such as embodied cognition, phenomenology and social constructivism. Explorations in this field have to some extent been tempered by the relative lack of scalability of such interventions, in terms of – for example – the cost of capital, as well as the learning curve and its consequential costs of time. It has only been since 2018 or so that these costs have begun to level off and show indications of falling, as – for example – open-source technologies and the capabilities of recent smartphones have progressed. In an increasing number of contexts for learning, specialised equipment no longer needs to be purchased, and the authoring of the learning objects is becoming increasingly democratized. With increasing scalability, it is also possible to use AR learning scenarios extensively in educational contexts. Against this background, it is important that we learn more about the concrete conditions of AR learning scenarios that lead to positive effects on affective and cognitive factors of learning.

It is from this framing that we have assembled this Special Issue of the British Journal of Educational Technology, with a view to better understanding the intersection of AR and learning. The issue provides an opportunity to highlight what we already know in this field, which areas in the research landscape appear ripe for exploration, and what future developments might be expected.

This Special Section presents a collection of multi-disciplinary studies which together represent leading edge thought from various scholars from around the world, on the potential contribution of AR to the learning sciences. We have taken care to choose exemplars which suggest how conversations at this intersection might move beyond the use of AR as a means of presenting visualisations to learners. Taken together, the case studies shed light not only on the concrete conditions under which AR-based learning can become effective, but also on the role of individual learning prerequisites and how they affect AR supported learning. The papers present studies from the subject domains of language teaching, history education, chemistry and physics education and vocational education.

The first paper by Cai and colleagues '*Interaction Analysis of Teachers and Students in Inquiry Class Learning based on Augmented Reality by iFIAS and LSA*' deals with the potential of AR in Inquiry-Based Learning (IBL). A case study will compare student-teacher interactions in an AR-based IBL setting with a more conventional IBL learning situation. In addition, the authors give implications on how AR support can be integrated into IBL in a meaningful way.

In the second article of the Special Section '*Semiotics, memory and Augmented Reality: History education with Learner-Generated Augmentation*' by Lim and Lim, AR-based learning is viewed from a student-centred perspective, in which learners create and use AR-based content for their own learning in the context of history education. In their study, the authors analyze student interviews regarding the perceived AR experience in the concrete learning situation. Furthermore, the artefacts created by the learners are systematically analysed.

The third article '*AR Videos as Scaffolding to Foster Students' Learning Achievements and Motivation in EFL Learning*' by Chen also deals with the use of AR to support students' learning. In concrete terms, the effect of AR-based scaffolding in the context of English as foreign Language (EFL) studies is examined. In an experimental study, the effects of a video-based and an AR-enhanced video-based learning opportunity are contrasted. The results of the study show that the AR-based learning condition not only leads to better learning success but also to higher learning motivation and satisfaction with the EFL course.

The use of AR-based learning opportunities in vocational education and training is the subject of paper four of the special section '*Some pedagogical observations on using augmented reality in a vocational practicum*' by Lester and Hoffmann. The authors present two examples of the use of AR in a chemical training plant. In the first example AR glasses linked to a remote computer are used to facilitate distant instruction, and in the second, mixed reality resources for learning a production operation are presented. Furthermore, implications for the use of AR in vocational training are derived.

Article five '*The Use of Augmented Reality to Foster Conceptual Knowledge Acquisition in STEM Laboratory Courses - Theoretical Background and Empirical Results*' by Altmeyer and colleagues deals with the effects of AR-supported learning in STEM laboratory courses at the university level. An approach is presented in which hands-on experiments in the context of IBL in physics education are supplemented by AR-based digital elements. In a pretest-posttest design the effects of an AR-based and a non-AR-based learning environment are contrasted in terms of perceived cognitive load, conceptual knowledge and usability.

The sixth paper '*Who can benefit from augmented reality in chemistry? Sex differences in solving stereochemistry problems using augmented reality*' by Habig is about the potential of AR to support students in handling scientific representations in chemistry at the university level. Against the background of frequently reported sex differences in terms of mental rotation, it is investigated whether sex-specific differences in AR support in context solving stereochemical problems are apparent and who can benefit from such support.

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