

PROMOTING INTRINSIC MOTIVATION WITH A MOBILE AUGMENTED REALITY LEARNING ENVIRONMENT

Josef Buchner¹ and Jörg Zumbach²

¹University College of Teacher Education Lower Austria, Mühlgasse 67, A-2500 Baden, Austria

²University of Salzburg, School of Education, Hellbrunnerstraße 34, A-5020 Salzburg, Austria

ABSTRACT

In this study the impact of a mobile augmented reality learning environment on motivation, learning effects and cognitive load was tested. Students participated in a two-hour history lesson while using their smartphones to turn static pictures into animations with an Augmented Reality (AR) application. Interest, perceived competence and perceived choice as indicators for intrinsic motivation were assessed. Results of the AR learning group were compared to a non-AR teacher-centered learning environment. The results reveal that augmented reality learning can promote intrinsic motivation and has an impact on history learning. Cognitive load has not been detected as a problem within the AR group.

KEYWORDS

Augmented Reality, Self-Determination Theory, Mobile Learning Environment

1. INTRODUCTION

Augmented Reality (AR) is one of the top educational technology trends since 2010. The Horizon Report (Johnson et al., 2010) assumes a positive impact on learning, creativity and education but the technology was not available on consumer devices at that time. This changed with the rise of smartphones, tablet computers and appropriate platforms (e.g. iOS, Android,...; Yuen, Yaoyuneyong, & Johnson, 2011, p. 120). Nowadays, everything a user needs is a mobile device with camera and an AR application (e.g., Aurasma). Recent surveys from Austria and Germany show that 95% of twelve to nineteen year old students own such a device and 75% of young adults (16-29) in Europe use the Internet on their mobile phone (Education Group, 2015; European Union, 2015; Medienpädagogischer Forschungsverbund Südwest (mpfs), 2016). In summer 2016 Pokémon Go made AR available for the masses and made this technology popular. Since then 750 million downloads of the app have been registered and more than five million active users keep the game still alive (Smith, 2018).

Azuma (1997) defines AR as the coexistence of real and virtual objects in the same space and with real time interaction. For Klopfer and Sheldon (2010) augmented reality (AR) is “(..) a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information” (Klopfer & Sheldon, 2010, p. 205). Milgram et al. (1994) developed a continuum (Figure 1) with two extremes, the real environment and the virtual environment.

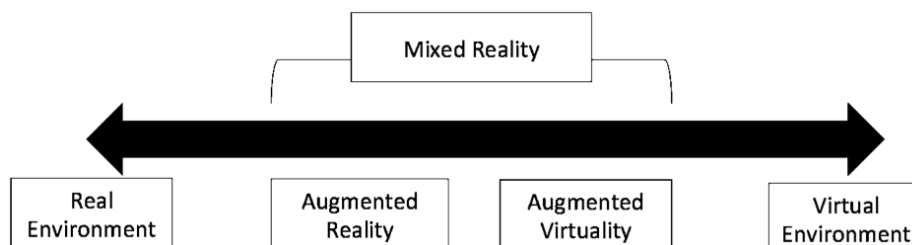


Figure 1. Reality-Virtuality Continuum, Own Representation, Based on Milgram & Kishino, 1994

In this Reality-Virtuality-Continuum, virtual environments are defined as environments that are totally simulated by technology (Yuen, Yaoyuneyong, & Johnson, 2011, p. 121). This side of the continuum is known as Virtual Reality (VR). Between both sides, technology enhanced environments are characterized as “mixed reality”. For AR, the real environment is used as background and computer-generated content is displayed. In Augmented Virtuality a computer-generated environment acts as background and real-world objects build an additional layer (Milgram & Kishino, 1994).

Many researchers have already shown that AR can have a positive impact for learning. As for all technology enhanced environments it is important to think about pedagogical aims and learning theories, which can promote the learning process with the help of this technology. For AR Dunleavy and Dede (2014) suggest situated learning theory and constructivism learning as the most important theoretical approaches. Learners can improve their knowledge and skills like problem solving while acting in a real-world and a social-context. Five conditions of constructivist learning theory can enhance learning with AR:

- Learning within relevant environments
- Enable social interaction
- Provide multiple modes of representation
- Provide self-directed and active learning
- Support metacognitive strategies

AR allows also creating problem-based learning environments. Problems can here be solved with collaborative learning approaches like role-play or jigsaw. Another benefit is the possibility to provide multiple learning opportunities, like leaving the physical space, observe new content, manipulate and analyze objects (Dunleavy & Dede, 2014).

Klopfer and Sheldon (2010, p. 86) summarize the potential of AR as „(...)to enable students to see the world around them in new ways and engage with realistic issues in a context with which the students are already connected.“ Dunleavy and Dede (2014) pointed out that there are typically two versions of AR possible for educators. Location-based AR is linked to GPS-enabled smartphones or devices, which locate the learner in a specific location. Then a multimedia content is displayed which provides relevant information’s about this spot. An example for such a location-based is environment is Wikitude (Yuen et al., 2011), which provides specific data about sights in a city or any other place (e.g., about a specific habitat when passing by a specific tree). The other version is vision-based AR. To project the virtual information a trigger image/object is needed. When this image/object is scanned with a camera, virtual objects like text, sounds, videos, animations, 3D models or images appear. An example here is a trigger image near a tree which shows a 3D model of the structure when the camera is focused on it (Dunleavy & Dede, 2014). In this research also a vision-based AR learning environment will be discussed.

2. AR IN EDUCATION

2.1 Impact on Learning Effects

Research showed that AR could support learning in a more effective way than other technology enhanced environments. If content is represented as 3D learners can manipulate objects and handle information’s in an interactive way (El Sayed, Zayed, & Sharawy, 2011). Collaborative AR applications can improve spatial abilities (Kaufmann & Schmalstieg, 2003; Kaufmann, Steinbugl, Dunser, & Gluck, 2005) and an authentic AR environment can help understanding dynamic models and complex causality (Rosenbaum, Klopfer, & Perry, 2007). The combination of visual and haptic experience makes AR interesting for the development of psychomotor-cognitive skills (Feng, Duh, & Billingham, 2008). For example, in clinical medicine an AR system collected data about learners’ performance. Subsequently the system transformed the information’s to visual and immediate feedback to support learners’ psychomotoric skills (Kotranza, Lind, Pugh, & Lok, 2009). An AR game on science allows students to organize, search and evaluate data and educated their skills in navigating primary and secondary information’s (Klopfer, 2008). Mathews (2010) describes a learning environment that helps students to navigate and participate in the digital media landscape by means of an AR simulation. Stanton et al. (2003) reported about AR in museum education and summarized that AR can contribute to student’s understanding of history in an authentic way. Ferrer-Torregrosa et al. (2016) compared a video-supported learning scenario to an AR supported one in anatomy learning. The students

learned about the muscles of the foot with videos or 3D models. The analysis of the survey indicated a more effective learning with the 3D graphics within the AR setting. Santos et al. (2016) designed a situated vocabulary learning content with ARToolKit (Kato & Billinghurst, 1999). Compared to a non-AR learning content no differences were found in a temporary post-test. A delayed test about vocabulary retention offered a bigger difference in favor of the AR condition.

Additionally to the improvement of content knowledge learning with AR can support collaboration, physical task performance and language learning (Radu, 2014).

2.2 Impact on Motivation

Several studies observed the influence of AR learning environments on students' motivation. Users showed a high enthusiasm while interacting with the AR experiences and reported a higher satisfaction compared to non-AR learning. Also the willing to repeat was higher within an AR setting even though it was more difficult than the offered non-AR environment (Radu, 2014). Santos et al. (2016) tested an AR model for vocabulary learning and found a positive impact on satisfaction and attention. Similar results have been detected by Freitas and Campos (2008), as they developed an AR learning system to teach the meanings of animal and wheeler words for 2nd grade students in Portugal. A visual art course about Italian Renaissance was realized with and without AR. The group learning with AR showed a moderately higher motivation compared to the non-AR learning group. Also an increased interest in and attention for the learning content has been found. Very important for the observed students was the control over the presented learning materials and the learner-centered tasks and activities, which made the whole experience more engaging for them (Di Serio, Ibáñez, & Kloos, 2013). An increase of interest has also been found by Sotiriou and Bogner (2008).

2.3 Limitations

If educators want to implement AR within their classrooms some issues have to be considered. From the technological perspective a device with camera and/or GPS is needed. Most of the applications are also addicted to Internet access. Also the instructional point of view must be considered and needs a change if AR is used in a learning process. A teacher-centered approach can hinder successful knowledge construction, thus a student-centered and explorative character of learning is necessary (Kerawalla, Luckin, Seljeflot, & Woolard, 2006; Wu, Wen-Yu Lee, Chang, & Liang, 2013). Important for teachers and lectures is the flexibility of the AR system. Many systems do not allow changes of the content therefore AR authoring tools are essential to regard the specific needs of the learners. Furthermore the use of AR can cause cognitive overload or the feeling of confusion because of the mixed perception of real and virtual environment (Wu et al., 2013). Attention tunneling, usability difficulties and learner differences are some other challenges to think about (Radu, 2014).

3. CASE STUDY AND RESEARCH QUESTIONS

Based on the findings of former research on learning with AR, this paper studies the impact of a mobile augmented reality learning environment on motivation, learning effects and cognitive load. Three research questions are posed:

First, the impact of the AR learning environment on the learners' motivation is explored. According to self-determination theory (Ryan & Deci, 2000a; 2000b), autonomy, competence and relatedness are the basic needs of humans. If these three needs are satisfied, our motivation to act is more intrinsic than extrinsic. This also applies to learning. Educators can design learning environments that take these needs into account. Free choice opportunities and direct feedback are just two ways for lecturers to support the feeling of autonomy and competence. Other indicators of intrinsic motivation are interest and enjoyment. Beside self-directed learning options Dunleavy and Dede (2014) point out that social experiences are important when learning with AR. Self-determination theory calls this a "social experience relatedness" which can be realized in every classroom when students are allowed to work together in teams. To examine intrinsic motivation the *Intrinsic Motivation Inventory* was designed (Ryan, 1982; Ryan, Mims, & Koestner, 1983). In this questionnaire

participants report about interest/enjoyment, perceived competence, perceived choice and pressure/tension as indicators for intrinsic motivation. It is assumed, that the provided learning environment can promote intrinsic motivation by comparison with a more traditional classroom setting (e.g., teacher-centered teaching).

Second, to measure the learning success a pre-and post-test was generated. We assume that the AR learning environment combined with the offered tasks can support the facilitation of historical knowledge.

Third, there are also challenges and burdens when AR is used in classrooms. Dunleavy et al. (2009) covered that learning processes with AR can cause cognitive overload because of the complexity the technology and tasks bring along. According to the Cognitive Load Theory the design of the learning material has an impact on the extraneous cognitive load, which can hinder the learning process (Sweller, 2005). To evaluate the cognitive load within this AR environment an adapted version of the NASA Task Load Index (Hart & Staveland, 1988) is used. With a five-point rating scale the items task requirement, effort in understanding content, mental effort, effort in navigation and stress are self-reported. The students fill the questionnaire after interacting with the learning environment. It is expected that the learners did not experience a high level of cognitive load through the AR elements and the learning tasks.

4. METHOD

4.1 Design and Sample

For this research a two-hour history lesson for students of a secondary school in Vienna was designed as a mobile learning environment with augmented reality elements. Participants used their own smartphones and earphones to experience the contents. The topic of the lesson was “Witch tracing at the beginning of modern times”. The design of the study is one-factorial with an experimental and a control group. The control group experienced a traditional classroom setting. A total of 23 learners, eight male and 15 female, participated in the AR group. In the control group 36 students, 21 female and 15 male participated. The average age in the AR group was 12.2 years ($SD = 0.42$), in the control group 14.74 years ($SD = 2.01$).

4.2 Procedure

At the beginning of the study, students installed the application *Aurasma* on their smartphones and entered it with a provided username and password. In teams of two they received a list of AR elements they had to completely check. On classroom wall there were trigger images placed by the teacher, every picture contained an AR element. Before the learning phase started a pre was administered. Subsequently, the learners moved around in the classroom and used the smartphones to turn the static pictures into animated ones. The static pictures were taken from diverse websites and all were under a creative commons or public domain license (e.g., a clip art visualization of a witch or the cover of the *malleus maleficarum*). Every trigger image provided a self-made whiteboard video that fitted exactly to the trigger. When the pupils focused their smartphones with the application on it, the images turned into the video. Every AR element (here: video) informed about specific subjects according to the topic of witch hunt. Every video offered a task for the pupils. One task, for example, was to analyze a historical picture about a witch trial. Another task was a rather closed task implemented within the learning application, for example a drag and drop quiz. At the end of the lessons the knowledge post test, the intrinsic motivation questionnaire and the NASA-Task Load Index questionnaire were applied. The intrinsic motivation questionnaire is an adapted German version of the *Intrinsic Motivation Inventory*. Wilde et al. (2009) found strong validity for the short scale of intrinsic motivation and recommended the scale for other learning scenarios. The questionnaire contains twelve items on five-point Likert-scales, three for every subscale (e.g., perceived choice).

The control group had a teacher-centered lesson. Here only the intrinsic motivation questionnaire was administered after the lesson to determine the motivational baseline.

5. RESULTS

The descriptive analysis of the short scale of intrinsic motivation and the NASA-Task Load Index were computed with SPSS Statistics 24. For the knowledge test every correct answer was rewarded with a point and an overall sum score was computed.

5.1 Motivation

Table 1 shows the descriptive results of the subscales assessing intrinsic motivation.

Table 1. Results of the Short Scale of Intrinsic Motivation – AR Group Compared to Control Group

Scale	AR Group		Control Group	
	Mean (SD)	Cronbach's Alpha	Mean (SD)	Cronbach's Alpha
Interest/Enjoyment	7.78 (1.86)	.83	5.09 (3.65)	.94
Perceived Competence	7.09 (1.16)	.52	5.39 (2.58)	.88
Perceived Choice	7.74 (1.57)	.71	2.72 (2.58)	.91
Pressure/Tension	2.04 (1.43)	.27	1.37 (1.31)	.48

The results in Table 1 show a high approval within the scales interest/enjoyment, perceived competence and perceived choice for the AR group, lower means for these scales have been found for the control group. These results tend to confirm the first research question. As a limitation the low value of *Cronbach's Alpha* (0.52) for the scale perceived competence within the AR group has to be mentioned. Thus, this sub-scale will be excluded from further discussion.

5.2 Learning Effects

In the pre knowledge test, students achieved 57 points (out of 184), i.e., 31% of the possible points. The results of the post-test reveal a difference of 64 points compared to the pre test. Students achieved here an average of 121 points (= 66%). Additionally a paired-samples t-test was conducted to compare the historical knowledge before and after the AR experience. There was a significant difference between the pre test scores ($M=2.48$, $SD=1.2$) and the post test scores ($M=5.26$, $SD=1.1$); $t(22)=-9.45$, $p = 0.000$.

5.3 Cognitive Load

The evaluation of the NASA Task Load Index tends to contradict the findings of Dunleavy et al. (2009). Table 2 shows the means for each item, *Cronbach's Alpha* for the whole questionnaire is 0.63. The answers ranged from 1 (= very) to 5 (= not at all).

Table 2. Results of the NASA Task Load Index

Item	Mean	Standard Deviation
Mental effort	2.30	1.22
Task requirement	3.26	1.14
Effort in understanding	4.30	1.02
Effort in navigation	4.22	0.99
Stress	4.52	0.99

The learners experienced approximately no stress or navigation problems within the mobile AR learning environment. Also the effort to understand the learning environment could be kept low. The offered tasks have been scored as mentally challenging, but as understandable and solvable.

6. SUMMARY AND DISCUSSION

AR as an educational trend is still not very common within classrooms. The rapid development of mobile devices (e.g., smartphones, tablets) made it possible for teachers and lecturers to integrate this technology in their teaching methods. In this study, AR elements have been offered to a history class while moving around on their own, experiencing a mobile and autonomous learning environment. The learner-centered approach is important when using AR for learning (Dunleavy & Dede, 2014). Benefits are autonomous learning and the feeling of competence. According to self-determination theory these perceptions within a learning environment can promote intrinsic motivation, ascertainable through interest/enjoyment, perceived choice and perceived competence (Ryan & Deci, 2000a; 2000b). Unbeneficial teacher-centered approaches can, however, hinder the learning success (Kerawalla et al., 2006). The results here show that learners rated the learning process as interesting, self-directed and perceived the feeling of competence. Compared to a non-AR and teacher-centered control group, the agreement for these elements of the self-determination theory was higher within the AR group. Therefore it can be stated that the AR learning environment as provided here was able to promote intrinsic motivation.

The influence of the environment on learning effects has been evaluated with a pre and post knowledge test. The scores in the post-test were much better (from 31% to 66%) than in the pre-test. A possible cognitive overload because of the AR learning was not detected.

Limitations of the study are the small sample size and the low internal consistency for the sub-scale of "Perceived Competence" within the AR group and the sub-scale "Pressure/Tension" for both groups.

Future research should also compare the facilitation of skills and knowledge between learning with and without AR. To summarize these findings, we argue that mobile learning environments with AR have a huge potential to motivate learners and to integrate mobile devices as trigger for self-directed learning processes. The latter is important for future generations of learners, because the availability and the use of such offerings will increase. Educators can act as role models here and show that the devices can also be used as learning tools. The benefits of AR are in the area of motivational support, the visualization of complex processes, and can help to foster the pedagogical shift from teaching to learning.

REFERENCES

- Di Serio, Á., Ibáñez, M. B., & Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education*, 68, 586–596. <https://doi.org/10.1016/j.compedu.2012.03.002>
- Dunleavy, M., & Dede, C. (2014). Augmented Reality Teaching and Learning. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Hrsg.), *Handbook of Research on Educational Communications and Technology* (S. 735–745). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4614-3185-5_59
- Education Group. (2015). 4. Oö. Jugend-Medien-Studie 2015. Abgerufen von <https://www.edugroup.at/innovation/forschung/jugend-medien-studie/detail/4-ooe-jugend-medien-studie-2015.html>
- El Sayed, N. A. M., Zayed, H. H., & Sharawy, M. I. (2011). ARSC: augmented reality student card - an augmented reality solution for the education field. *Computers & Education*, 56(4), 1045–1061.
- European Union (Hrsg.). (2015). *Being young in Europe today*. Luxembourg: Publications Office of the European Union.
- Feng, Z., Duh, H. B.-L., & Billingham, M. (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. Gehalten auf der 7th IEEE/ACM international symposium on mixed and augmented reality (ISMAR), Cambridge, UK. <https://doi.org/http://dx.doi.org/10.1109/ismar.2008.4637362>
- Ferrer-Torregrosa, J., Jimenez-Rodriguez, M. A., Torralba-Estelles, J., Garzon-Farinos, F., Perez-Bermejo, M., & Fernandez-Ehrling, N. (2016). Distance learning ects and flipped classroom in the anatomy learning: comparative study of the use of augmented reality, video and notes. *BMC Medical Education*. <https://doi.org/10.1186/s12909-016-0757-3>
- Freitas, R., & Campos, P. (2008). SMART: a System of augmented reality for teaching 2nd grade students. In *Proceedings of the 22nd British Computer Society Conference on Human-Computer-Interaction (HCI 2008)* (S. 27–30). Liverpool John Moores University, UK.
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of experimental and theoretical research. In P. A. Hancock & N. Meshkati (Hrsg.), *Human mental workload* (S. 139–183). Amsterdam: North Holland.
- Johnson, L., Levine, A., Smith, R., & Stone, S. (2010). *The 2010 Horizon Report*. Austin, Texas: The New Media Consortium. Abgerufen von <https://www.nmc.org/pdf/2010-Horizon-Report.pdf>

- Kato, H., & Billinghurst, M. (1999). Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *Proceedings of IEEE and ACM International Workshop on Augmented Reality* (S. 85–94). San Francisco, CA.
- Kaufmann, H., & Schmalstieg, D. (2003). Mathematics and geometry education with collaborative augmented reality. *Computers & Graphics*, 27(3), 339–345. [https://doi.org/http://dx.doi.org/10.1016/s0097-8493\(03\)00028-1](https://doi.org/http://dx.doi.org/10.1016/s0097-8493(03)00028-1)
- Kaufmann, H., Steinbugl, K., Dunser, A., & Gluck, J. (2005). General training of spatial abilities by geometry education in augmented reality. *Annual Review of CyberTherapy and Telemedicine. A Decade of VR*, 3, 65–76.
- Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). “Making it real”: exploring the potential of augmented reality for teaching primary school science. *Virtual Reality*, (10), 163–174.
- Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. Cambridge: MIT Press.
- Klopfer, E., & Sheldon, J. (2010). Augmenting your own reality: student authoring of science-based augmented reality games. *New Directions for Youth Development*, 128, 85–94.
- Kotranza, A., Lind, D. S., Pugh, C. M., & Lok, B. (2009). Real-time in-situ visual feedback of task performance in mixed environments for learning joint psychomotorcognitive tasks. In *8th IEEE international symposium on mixed and augmented reality (ISMAR)* (S. 125–134). Orlando, FL. <https://doi.org/http://dx.doi.org/10.1109/ISMAR.2009.5336485>
- Mathews, J. M. (2010). Using a studio-based pedagogy to engage students in the design of mobile-based media. *English Teaching: Practice and Critique*, 9(1), 87–102.
- Medienpädagogischer Forschungsverbund Südwest (mpfs) (Hrsg.). (2016). JIM 2016. Jugend, Information, (Multi-) Media. Basisstudie zum Medienumgang 12- bis 19-Jähriger in Deutschland. Retrieved from https://www.mpfs.de/fileadmin/files/Studien/JIM/2016/JIM_2016.pdf
- Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information System*, 77(12), 1321–1329.
- Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing*, 18(6), 1533–1543. <https://doi.org/10.1007/s00779-013-0747-y>
- Rosenbaum, E., Klopfer, E., & Perry, J. (2007). On location learning: authentic applied science with networked augmented realities. *Journal of Science Education and Technology*, 16(1), 31–45. <https://doi.org/http://dx.doi.org/10.1007/s10956-006-9036-0>.
- Ryan, R. M. (1982). Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory. *Journal of Personality and Social Psychology*, 43, 450–461.
- Ryan, R., Mims, V., & Koestner, R. (1983). Relation of reward contingency and interpersonal context to intrinsic motivation: A review and test using cognitive evaluation theory. *Journal of Personality and Social Psychology*, 45, 736–750.
- Ryan, R. M., & Deci, E. L. (2000a). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology*, 25, 54–67. <https://doi.org/doi:10.1006/ceps.1999.1020>
- Ryan, R. M., & Deci, E. L. (2000b). Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. *American Psychologist*, 55(1), 68–78.
- Santos, M. E. C., in Wold Lübke, A., Taketomi, T., Yamamoto, G., Rodrigo, M. M. T., Sandor, C., & Kato, H. (2016). Augmented reality as multimedia: the case for situated vocabulary learning. *Research and Practice in Technology Enhanced Learning*. <https://doi.org/10.1186/s41039-016-0028-2>
- Smith, C. (2018). 85 Incredible Pokemon Go Statistics and Facts (January 2018). Retrieved from <https://expandedramblings.com/index.php/pokemon-go-statistics/>
- Sotiriou, S., & Bogner, F. X. (2008). Visualizing the invisible: augmented reality as an innovative science education scheme. *Advanced Science Letters*, 1, 114–122.
- Stanton, D., O’Malley, C., Huig, K., Fraser, M., & Benford, S. (2003). Situating historical events through mixed reality. In B. Wasson, S. Ludvigsen, & U. Hoppe (Hrsg.), *Designing for Change in Networked Learning Environments* (S. 293–302). Dordrecht: Kluwer Academic Publishers.
- Sweller, J. (2005). The redundancy principle in multimedia learning. In R. E. Mayer (Hrsg.), *The Cambridge Handbook of Multimedia Learning* (S. 159–167). Cambridge: University Press.
- Wilde, M., Bätz, K., Kovaleva, A., & Urhahne, D. (2009). Überprüfung einer Kurzsкала intrinsischer Motivation (KIM). *Zeitschrift für Didaktik der Naturwissenschaften*, 15, 31–45.
- Wu, H.-K., Wen-Yu Lee, S., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, 62, 41–49.
- Yuen, S. C.-Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented Reality: An Overview and Five Directions for AR in Education. *Journal of Educational Technology Development and Exchange*, 4(1). <https://doi.org/10.18785/jetde.0401.10>