# Augmented reality in teacher education. A framework to support teachers' technological pedagogical content knowledge

# *La realtà aumentata nella formazione degli insegnanti. Un framework per supportare le competenze tecnologiche, pedagogiche e disciplinari degli insegnanti*

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**ABSTRACT** In this article the use of Augmented Reality (AR) as an educational technology in classroom applications and teacher training is suggested. AR is a combination of real-world information with digital information overlaid. A review of the research literature on AR learning environments reveals that in most studies AR contributes to successful learning and increased motivation. An evaluation study reveals that teachers' ability of self-concept for implementing AR within their classrooms is closely related to educational technology and the technology itself in general. Here, teachers need orchestrated support for implementing AR in classrooms. Subsequently, a model for design and implementation of AR classroom application is suggested. These suggestions are illustrated by some exemplary AR classroom learning environments. This paper closes with recommendations for future research, in which more basic and controlled experimental research is needed in order to get a valid impression about the benefits of AR as classroom technology.

**KEYWORDS** Augmented Reality; Instructional Design (ID); Teacher Education; Technological Pedagogical Content Knowledge (TPCK).

**SOMMARIO** In questo articolo, viene suggerito l'utilizzo della realtà aumentata (AR) come applicazione da impiegare in classe. L'AR è una combinazione di informazioni provenienti dal mondo reale e da quello digitale. La letteratura internazionale indica come l'AR contribuisca allo sviluppo di apprendimenti significativi e della motivazione all'apprendimento stesso. La capacità di utilizzo dell'AR in classe da parte degli insegnanti è strettamente correlata all'attitudine dell'utilizzo della tecnologia in senso generale. Gli insegnanti necessitano di supporto formativo per implementare l'utilizzo dell'AR in classe. Di conseguenza, in questo articolo, vengono suggerite modalità ed esemplificazioni per progettare e supportare l’applicazione dell’AR in classe. In conclusione, vengono fornite indicazioni e raccomandazioni per futuri studi e ricerche da focalizzare sui vantaggi e i benefici nell’utilizzo dell’AR in classe.

**PAROLE CHIAVE** Realtà Aumentata; Progettazione Didattica; Formazione degli Insegnanti; Competenze Digitali degli Insegnanti.

## 1. INTRODUCTION

With the development of new information and communication technologies (ICT), their impact on educational issues is often discussed. With the broad availability of technology developments, the need for Instructional Design (ID) considerations about how to incorporate these technologies within educational settings increases. This debate also refers to a technology that has emerged over the past decade and is known as Augmented Reality (AR).

AR refers here to all technologies that enable an overlay and mix of digital content with a real-world perception (Yuen, Yaoyuneyong, & Johnson, 2011). AR is thereby open to nearly every digital content form, like two- or three-dimensional image representations (including images, videos, animations or simulations), text, audio, tactile and olfactory stimuli (e.g., Wu, Lee, Chang, & Liang, 2013; Yuen et al., 2011). As distinct from other technological developments like simulations or other technology-based learning environments, AR cannot be considered as a “single medium”. Rather, it is designed to interweave additional information with the real world and augments analogue information with digital data. As such, AR is not a virtual reality experience but always incorporates the real world together with an overlay of or enriched enactment of digital information (e.g. Kesim & Ozarslan, 2012; Radu, 2014).

The development and application of Augmented Reality is not new. In the 1990s Milgram and Kishino (1994) discussed this technology as part of a continuum between the real world and the virtual world. They referred to the term Mixed Reality as a term for representations that were positioned in between two poles (see Figure 1). Mixed Reality contains two representations where the augmentation of the real world is referred to as AR, whereas the augmentation of the virtual world with real world objects is called as Augmented Virtuality.

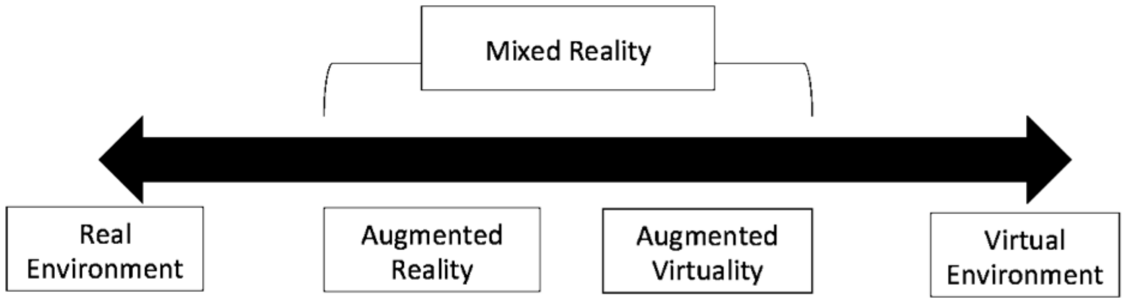


**Figure 1.** Reality-Virtuality Continuum (Milgram & Kishino, 1994).

Meanwhile, AR has become well established within the corporate world (e.g., as supportive tools in manufacturing, warehousing; Lee, 2012); but there is also a huge potential for using this technology within educational scenarios (Bower, Howe, McCredie, Robinson, & Grover, 2014). It is the high level of interactivity of this medium that opens up a huge range of possible applications of AR within educational settings.

Here also a wide range of possibilities for implementation of this technology within learning environments is possible. A rather basic application is the possibility to enrich "traditional" media with additional digital information, e.g., to offer QR-codes within a textbook that enable readers to see a video on a digital device (e.g., smartphone or tablet) that accompanies the text. This form of AR is known as vision-based because objects are used as so-called trigger images. Beside QR-codes, other objects or indicators may also be used to trigger the technology to provide augmentation. Such triggers in the real world may be pictures or nearly any real-world objects (e.g., a globe, a building etc.). Usually, learners have a mobile device like a tablet, smartphone or AR-glasses that contains a camera They then point the camera towards an object and the AR software provides the augmentation to the real-world object. The second form of AR is location-based. Here the device requires access to the Global Positioning System (GPS), because the presentation of the digital information is associated with a physical location (Dunleavy & Dede, 2014). Rather high end-approaches, such as Smartglasses like the Hololens or the Vuzix Blade, use AR-glasses as technologies that directly display visual and/or auditory information as part of the real-world experience

Although AR has become increasingly fashionable in the corporate world and also within the entertainment sector, its application within education is rather rare. Pre-service and in-service teacher training do not yet really focus on classroom application of such technologies. A major reason for this might limited access to technological equipment for rather high-end AR applications. Nevertheless, even basic applications like the use of smartphones or tablets for incorporating AR within the classroom still mostly play a minor role in teacher training and thus in daily school practice. However, to accommodate the needs of future generations, the potential of AR as educational technology might be able to provide meaningful learning opportunities. The present would be a good time to increasingly integrate such offers in the education and further training of teachers, since the barriers to the use of AR are falling with rapid technological development. Almost all students now have access to the technology they need to learn with AR (i.e. a smartphone with Internet connection and a camera function), either because they already have their own mobile devices or because they are gradually being provided with them by their school (e.g. Fraillon et al., 2019).

Beside the essential technological aspects of AR and the possibility for creating AR-based learning environments, there are major questions to be addressed regarding the educational purpose of this technology. Prior research has provided evidence that educational use of AR can have an impact on different variables involved in learning processes, like motivation, learning achievement, or visualization of hard-to-imagine content (Akçayır & Akçayır, 2017; Billinghurst et al., 2015; Garzón & Acevedo, 2019)learner type (e.g., K-12, higher education, and adult. Klopfer and Sheldon (2010) summarize the potential of AR as being "*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"* (p. 86). This potential, applied wisely, has direct implications as the meta-analysis provided by Radu (2014) reveals. The author presents strong evidence that different forms of AR (Smartphone with GPS, without camera; Smartphone with GPS and camera; webcam with desktop PC/Projector; or head-mounted display) can contribute to sustainable learning experiences from a cognitive, embodied cognition or a motivational perspective. By integrating multiple representations, AR can contribute to learners' construction of spatial or temporal inferences between information, enabling them to interact with the learning content or to drawing attention to relevant information resources (Bower, Howe, McCredie, Robinson & Grover, 2014; Radu, 2014). Nevertheless, as Kerawalla, Luckin, Seljeflot and Woolard (2006) point out, a key condition for successful AR classroom implementation is teacher behavior. Teacher-centered instructional approaches might have a negative impact on students' AR experience and thus might hinder successful knowledge construction (see also Radu, 2014). For Dunleavy and Dede (2014), situated learning and constructivist learning theory are relevant when AR is used as an instructional tool. In this paradigm, the learners are part of a physical and social world that facilitates metacognitive learning processes like active observation and that enables interactions with multimedia learning materials. The question remains as to how the benefits of AR can be brought into classrooms. As in most cases of new technology introduction, several requirements have to be met. Such requirements include basic technological issues (e.g., availability and accessibility of hardware, internet access, etc.), but also the technological skills of students and teachers (Akçayır & Akçayır, 2017, pp. 7–8). However, the major question that arises concerns Instructional Design (ID) models for implementing well-designed technology-based learning environments. Thus, teachers not only have to make a basic decision whether to use AR or not, but rather to decide under which premises, for what audience, for which content, and how to re-design the available content to match it with the curriculum (Silva et al., 2018; Silva et al., 2019). Subsequently, other decisions referring to the choice of available applications or self-made AR have to be made (e.g. Bacca et al., 2019). In order to professionally implement all the above mentioned considerations and decisions, Technological Pedagogical Content Knowledge (TPCK) is essential (Mishra & Köhler, 2006). In order to answer the question as to how this knowledge can be characterized within the domain of AR use, the authors have conducted a review of AR implementation within different educational subjects. This review refers to learning outcomes, motivation and learner satisfaction, and provides an answer to the question as to why this technology should be implemented within specific classroom settings.

Another key question is how teachers' skills can be fostered to meet all these abovementioned requirements to bring AR into their classes. Here, an example for a prototype in-service teacher-training course is presented using a learning-by-design approach (Koehler & Mishra, 2005). A major research question here was how this approach can contribute to motivate teachers and support them in designing their own digital learning materials.

## 2. AUGMENTED REALITY IN EDUCATION

AR as a learning and instructional tool provides huge potential for designing and/or enriching innovative learning environments. Such environments not only allow students to learn individually, but also to interact with real and virtual objects in a collaborative way, engaging them through differential learning approaches (e.g. game-based learning, problem-based learning) and providing them with experiences which are not possible with other media (Wu et al., 2013). Kerawalla et al. (2006) described an AR learning environment about the solar system, rotation of the Earth, position of the sun, sunset and sunrise. The learning environment provided the possibility to interact with 3D objects to understand day rise and nightfall. An evaluation of this learning environment showed that especially the interactivity provided, i.e., the opportunity to manipulate the AR elements, supported basic understanding processes. In another study, AR was used to support understanding of the relation between physical 3D objects and their projections in an engineering graphic course. Here, the technology provided 3D models of typical geometrical objects. Compared to a learning scenario with traditional screen representations, learners using AR showed higher engagement and significantly increased learning performance (Chen et al., 2011).

Beside individual application, AR can also be used collaboratively by connecting learners. Mobile devices can be used as shared displays while interacting with the content. Freitas and Campos (2008) designed an AR experience for primary school students providing this possibility. The learners were given the task of identifying different transportation categories and animals. The basic design of the AR unit was like a TV game show in which the students had to make a decision about the category based on 3D models presented in the learning environment. The authors found evidence for increased motivation and knowledge acquisition. Another remarkable observation was that the AR game learning environment encouraged the whole class to collaborate. Similar results were found by Morrison et al. (2011) during a navigation task with an

AR map. Compared to a non-AR navigation task, student collaboration was more intense and more effective with an AR application.
In the AR simulation Environmental Detectives (Squire & Klopfer, 2007), collaborative learning was fostered by assigning different roles to students. Students had either to take the role of a scientist, an environmental investigator or an environmental activist. Depending on each role, different information data was available to learners that had to be taken together in order to accomplish given tasks collaboratively. Environmental Detectives provides a genuine example for the implementation of AR technology within a game-based learning environment. Squire and Jan (2007) define game-based or gamified AR experiences as *"[…] games played in the real world with the support of digital devices that create a fictional layer on top of the real world context"* (p.6). Commercial games have already used this mixed reality, for example in The Machines. Users just point their smartphone or table camera on a desk and a virtual world with humans, cars, streets and more is visible on the display. For science education Squire and Jan (2007) used the AR game Mad City Mystery to foster scientific reasoning. The main plot of the game is a murder mystery where students have to investigate the case. Within the learning scenario students interact with virtual characters, ask them questions and learn about the effects of human influence on environmental issues. After the game, the students had to present their findings and argue for their results. The design study found positive effects on the development of students' scientific literacy and their argumentation skills. The AR game Outbreak @ The Institute provides players with an AR environment featuring virtual personalities, virtual diagnostic laboratories and medicine. The aim of the game is to fulfil a specific role as a medical doctor, a medical technician or a public health expert and help to stop the spread of an infectious disease. Evaluation of this approach revealed that students experienced the learning environment in a realistic way. In addition, participants felt personally more involved in the scenario as in traditional settings (Rosenbaum et al., 2007). Liu, Tan, and Chu (2009) used AR and radio frequency identification (RFID) for a problem-based learning approach. The students used computers and PDAs to experience multimedia elements, for example 3D models of mandarin ducks. Compared to a non-AR group, the experimental group performed better in a pre-post-test comparison. The authors summarized that mobile learning environments and tasks, enriched with immersive learning experiences like AR, can foster problem-solving skills and the acquisition of knowledge (Liu et al., 2009).
Making invisible things or information visible is one of the most important advantages of AR compared to other media. Research experiences have centred especially on the domain of spatial structures and functions. Most of studies here compared AR learning environments with traditional textbook representations. Vincenzi et al. (2003) compared three different learning environments about the function of aircraft turbines: a video, a text and an AR-application. Post-test results reveal better immediate and delayed knowledge retention rates among the students in the AR-condition. Within the domain of chemical structures, Chen (2006) found evidence for improved learning with AR compared to a textbook approach. Similar experiments with similar findings have been conducted by Sin (2010), Seo et al. (2006) and Nischelwitzer et al. (2007). In all their studies (about the solar system, human anatomy or about volcanoes), learning with AR was more effective than learning with traditional textbooks. Beside science education setting, the use of AR has also be shown to be effective in language learning (e.g., Chen et al., 2007; Freitas & Campos, 2008; Liu et al., 2009).
Another approach of AR as a learning tool is to combine visual and haptic tasks. Kotranza, Lind, Pugh, and Lok (2009) designed an environment for clinical medicine where touch sensors placed on a physical environment (a body simulator) generated data about learners' performance. Based on these data, learners received visual feedback through AR in order to improve psychomotor actions.
Another area of research has been pursued at the interface of motivation and ICT. Several studies indi-

cate that technology enhanced learning can promote motivation, attention and interest (for an overview see Pittard, Bannister, & Dunn, 2003). When students learn with AR, they often show increased intrinsic motivation, report a high level of satisfaction with the learning experience and are also willing to repeat a lesson, even if the AR program is experienced as more difficult than the non-AR one (Radu, 2014). A positive impact on satisfaction and attention in vocabulary training with AR was found by Santos et al. (2016). Di Serio, Ibáñez, and Kloos (2013) offered students AR learning materials combined with learner-centered tasks and gave them control over their learning. This setting made the AR experience more interesting to students, which resulted in increased engagement during the learning process. According to Self-Determination Theory (Ryan & Deci, 2000), freedom of choice (e.g. the feeling of autonomy) is one way to promote intrinsic motivation in educational settings. An increase in interest levels and the feeling of competence was found by Buchner & Zumbach (2018) in the domain of history learning.

All the above-described approaches have a trait in common: teachers and lecturers have provided AR teaching materials for students to learn from. To the contrary, Mathews (2010) used a studio-based learning approach in which the students changed role from learners to designer-learners. First the students visited a workshop to learn about their city and possibilities to document a walkthrough. After that, they played some AR games to get comfortable with the technology. In the creation process they designed their own AR game involving redesign ideas for the city and the spaces they visited. All the materials, like videos, pictures, 3D models were created by the students and used for their own AR games. Mathews (2010) argues that mobile devices, the Internet and other new forms of digital technology are part of students' daily life and thus they must learn how to deal with the current and future challenges of digitalization. Therefore, he postulates, it is necessary to provide learning experiences which go beyond mere consumption. Other authors also recommend using AR as an instructional tool and as a practical technology that can encourage a learning by a learning-by-design approach (e.g., Ke, 2014; Kolodner et al., 2003).

## 3. FOSTERING TEACHER'S AR-RELATED TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPCK): A TECHNOLOGY-BY-DESIGN APPROACH

The preceding review of the literature on learning and teaching with AR reveals that up to now research has focused on student learning. There is hardly any literature and no empirical results available about how to systematically develop *teachers* TPCK with regard to AR. Nevertheless, this is crucial for successfully implementing AR within classrooms. For example, in Silva et al. (2019, p. 4), teachers' lack of pedagogical knowledge as well as technological knowledge are mentioned as obstacles for AR classroom implementation. Koehler and Mishra (2005) criticize the dominance of a focus on mere technological skills within teacher training when planning, conducting and evaluating technology-based instruction. A major issue here is that these technology-focused approaches are mostly separated from real pedagogical problems. To overcome this divide between technological and educational training, the Learning Technology by Design approach is suggested, which confronts teachers in their training with authentic pedagogical problems (Mishra & Koehler, 2005). Within this approach participants have to use and adopt technology to design learning environments that respond to specific instructional goals. Nevertheless, the technology used is not the focus of the considerations but should be used specifically to solve a previously identified pedagogical problem. An example of the Learning Technology by Design approach is the development of online courses provided by Koehler, Mishra and Yahya (2007). Here participants are required to conduct their own research about instructional methods that can be used in online learning environments and, thus, acquire skills about how a learning management system is working and investigated the potential of audio feedback and web-based PowerPoint presentations (Koehler, Mishra, & Yahya, 2007). Other applied examples refer to the creation of movies or the redesign process of educational websites (for an overview see Mishra & Köhler, 2006).

For this research study, the Learning Technology by Design-approach was used within an in-service teacher-training course about classroom implementation of AR. The seventeen teachers who participated in this course had never before had any direct experience with AR, but rather had rudimentary information about this technology. A basic rationale for the course was to have teachers experience the technology on their own and to experience how AR-based learning feels. The course topic was "Multimedia Development" and was a first prototype. Based on the TPCK model, the overall learning objective was the design of a digital artifact based on a specific instructional approach matching the curriculum that participants currently teach in their schools. The course structure that was adopted followed the CIOSC-Approach (Confrontation, Information, Organisation, Self-directed Learning, and Control. This is based on the KIOSK approach with the German-language acronym: Konfrontation, Information, Organisation, Selbstgesteuertes Lernen, Kontrolle (Teml & Teml, 2006). The training begins with the C-phase (Confrontation) followed by the I-phase (Information). Participants are confronted with AR and some examples of this new technology. In the information phase the trainer provides a small presentation about pedagogical methods (e.g. Flipped Classroom, Just-In-Time-Instruction) and how technology can support these approaches. The focus was set on digital educational videos, which can be used for both the Flipped Classroom and Just-In-Time-Instruction. Instead of delivering different types of educational video, their production and corresponding evaluation criteria, this information has to be worked out as AR elements. Subsequently, in the OS-phases (OS = Organization and Self-directed learning) participants were arranged in groups of four and had the opportunity to experience AR on their own by means of the application HP Reveal. Participants experienced an AR-based learning environment that was image-based and engaged in mobile learning by the use of smartphones. The trigger-images were placed throughout the building at a University College of Teacher Education; each static picture appeared as an animated one when scanned with the app. Participants moved around in teams, pointed their mobile device camera at the pictures and learned about laying-techniques, green-screen video, animations, interactive whiteboards, length and design criteria for educational videos. After the AR learning experience, all the teams met up with the trainer for feedback and control of learning progress (Control).

Afterwards, participants' own design process started (next OS phase of the CIOSC-approach). The same teams began writing storyboards to plan their own educational videos. They searched for images to visualize the specific content they selected, opted for a video type and recorded it collaboratively.

All in all eight videos were produced, each shorter than six minutes (Guo, 2013). Other design principles, like storytelling, visualization and interactivity were also taken into account.

After their own AR experience, all participants decided to augment their self-created videos and integrated them within a just-in-time-instruction approach. At the end of the training, each team presented their self-designed learning environment.

The development of TPCK is a process which needs a step-by-step introduction. AR can be one part of the ID here that supports teachers by developing ideas and concepts on how technology can be used in their classrooms. The possibility of the experience made it easier for them to understand how AR can contribute to learning processes.

The impact of the training as described above was evaluated by means of a delayed post-test half a year later (N = 15; 5 males, 10 females). Here data about their motivation, their ability self-concept (ASC) and their attitude towards AR as an educational technology were measured.

In order to assess participants' motivation, a German version of the Intrinsic Motivation Inventory (Ryan, 1982) was used (Wilde, Bätz, Kovaleva, & Urhahne, 2009). The short scale of intrinsic motivation questionnaire examines perceived Interest/Enjoyment, Perceived Choice and Pressure/Tension. For assessing the impact of the training on learners' ability self-concept, a modified version of a German inventory was applied (Schöne et al., 2002). Here three subscales were modified in order to assess participants' general ability self-concept regarding educational technologies, their ability self-concept regarding AR and their ability self-concept with regard to their AR-specific TPCK ability self-concept.

| Scale | Mean (SD) | Cronbachs' Alpha |
|---|---|---|
| Interest/Enjoyment | 4.56 (1.05) | 0.99 |
| Perceived Competence | 4.27 (0.86) | 0.91 |
| Perceived Choice | 4.29 (1.03) | 0.94 |
| Pressure/Tension | 1.30 (0.41) | 0.69 |
| Ability Self-Concept Educational Technology | 3.98 (0.62) | 0.76 |
| Ability Self-Concept AR-technology | 3.88 (0.70) | 0.87 |
| Ability Self-Concept AR-related pedagogical technological content knowledge | 3.78 (0.71) | 0.92 |

**Table 1.** Descriptive data of course evaluation measures (1 = very low to 5 = very high).

The results in Table 1 show the mean values, standard deviations and Cronbach's Alpha for the scales surveyed. The small number of participants means that the data must be interpreted carefully, and conclusions cannot be generalized. The mean values are above the mean for all scales except perceived pressure, suggesting that the items collected were agreed to a large extent. In sum, the collected data of the intrinsic motivation questionnaire reveal that the workshop seems to have been perceived as intrinsically motivating by the in-service teachers without generating an atmosphere of pressure. With regard to the development of TPCK, outcomes show also a homogenous picture. The questionnaire aims at assessing the development of participants' ability self-concept within three dimensions. In all three dimensions, values were close to the upper end of the scale and thus indicate a high level of competence experience. In order to assess how ability self-concept (with regard to Educational Technology in general and AR technology specifically) and AR-related TPCK are related, a correlational analysis was conducted. Here, Educational Technology ability self-concept (ASC) is strongly correlated with AR-ASC ($r = 0.85$, $p < 0.001$) and AR-TPCK ASC ($r = 0.78$, $p = 0.001$). Also, AR-ASC and AR-TPCK ASC show very high correlation ($r = 0.77$, $p = 0.001$).

Taken together, these evaluation outcomes indicate that training within the area of educational technologies for applied use within the classroom should not focus only on the technology itself, but should rather take into account the technology itself AND the technological pedagogical content knowledge (TPACK), which refers to the specifics of the content and the specifics of the technology (here: AR). In addition to the quantitative assessment, teachers were also asked about their actual and potential use of AR within their classrooms. About 27% indicated that they had already implemented AR into their teaching after the training, and about 87% were planning to do so, or continue to do so.

Participants were also asked about their experience in learning (more) about AR and their further needs to implement it in their classrooms. The teachers pointed out that the motivational factor is most important to them. The idea of "bringing pictures to life" was a particularly key motivation for most of them. The combination of movement and learning during class was also a major incentive for using AR. Most reported negative issues regarded technological problems like unstable Internet connection. Regarding implementation of AR in the classroom, participants focused on two major issues. First, they need enough (and maybe more) time to prepare and produce AR-based learning environments. Second, they need more training in how to use AR for the specific requirements of the subjects and the curricula they teach. A model has been developed in order to support these processes and this is described hereafter.

## 4. A MODEL FOR THE USE OF AR AS INSTRUCTIONAL TECHNOLOGY

As in every ID issue, the question arises as to when and under what circumstances the use of specific instruction technologies is suitable. With particular attention to the premises of the TPCK-Model (Angeli & Valanides, 2009; Mishra & Köhler, 2006), detailed analysis is needed of how AR can contribute to learning environments considering pedagogical content knowledge and the content itself. According to Schott (1991), the choice of specific instructional media and their development depends on a prior sequence of decisions within the ID process. These decisions include basic processes of needs assessment, definition of overall learning objectives, instructional analysis, definition of specific learning objectives, and choice of instructional method/strategy. These stages during the ID process are already at the interface of Pedagogical Knowledge and Pedagogical Content Knowledge: during instructional analysis it is necessary to determine what content becomes part of a learning environment and what does not. In this regard, there is a basic approach deriving from Science Education, namely so-called "Didactical Reconstruction" (Kattmann, Duit, Gropengießer, & Komorek, 1997). The basic idea of this approach is to reduce the complexity of a specific content area in order to make it appropriate for target audiences with no or little prior knowledge within the domain. Kattmann et al. (1997) suggest three steps for reconstructing content from a didactical perspective. First, a detailed instructional analysis of the content from a scientific point of view has to be conducted. Here, instructors also have to review the domain with regard to state-of-the-art research. From a pedagogical content knowledge perspective, a first review decides which content should be included and which excluded. In a second step, characteristics of the target group are analysed. This analysis refers to cognitive prerequisites (e.g., prior knowledge), but also motivational or affective variables that might be relevant. Another issue here that needs to be identified is position within the curriculum and which prerequisites and content can be used to build on. The third step is didactical reconstruction, which is the adaptation of the content as identified and selected in the first step from a pedagogical content knowledge perspective for the targeted audience. At this stage, decisions about the content and the didactical approach are made. Subsequently, the choice of appropriate media and, if necessary, their production, has to be made. These choices include all prior issues addressed during the process of instructional planning.

It is argued that the implementation of Augmented Reality is mainly based on three dimensions: the focus of the AR, the didactical/instructional approach, and the degree of enrichment provided by the AR.

The focus of the AR refers to the content that is presented in the augmentation. Basically, we distinguish here between a focus on the primary content that is extended by means of the AR and a focus on the augmentation. A focus on the primary content means that the AR is primarily supplementary to any content that exists in physical life. An example of primary content here would be any information, object or sight that provides the main focus of interest, whereas the AR presents additional or further information. A possible application could be a painting in an art museum, where the AR presents additional information about the painting and the artist. The second focus is the AR itself, where the real environment provides an anchor for the information presented in the AR, but the main information is provided within the virtual space. Minecraft AR, Virtuali-Tee or industrial applications are examples here (e.g., Martín-Gutiérrez, Mora, Añorbe-Díaz, & González-Marrero, 2017; Serin, 2017). While in Minecraft AR the real-world context is rather negligible, it still might provide an important anchor. In VirtualiTee (Serin, 2017), a QR-Code is provided on a t-shirt that enables mobile devices to display a layer on the person wearing the shirt with a simulation of the human body and the possibility to examine the body. Here, the main information is not the real world but rather the simulated information presented in the augmentation. Another example comes from the area of construction tasks, where the information necessary for fixing a bug or mounting parts together is provided in an augmented layer.

The didactical or instructional approach is based on pedagogical content knowledge or general pedagogical knowledge on how we learn. It refers to the way that AR is implemented within the learning environment and how it contributes to students' accomplishing learning objectives. From our point of view, this is a very important aspect, as we can look back on a long tradition of research in the field of learning with technology and multimedia (e.g. Clark, 1983; Mayer, 2019). Today we know that it is not the medium that is decisive for learning but the instructional approach chosen with regard to the learning objectives (Mayer, 2017; Mayer, 2008). For this reason, AR can be used in many different ways, both in informal learning contexts and basic instructional-design models. One example of the latter is Just-in-Time-Instruction (JITI; Novak & Beatty, 2017). JITI refers to a cycle where learners usually have to work on a pre-class assignment resulting in a student response. The response is analysed by the instructor, who provides in-class feedback and further in-class content based on the analysed needs. The design of AR learning environments might be able to support JITI by using the augmentation based on the actions performed by students and supporting them with the information needed to continue within a real world learning environment. Other approaches to instruction where AR might be suitable to support learner-centered environments are experiential learning (Lindsey & Berger, 2009) or problem-based learning (Savery, 2009). Learners, for example, might be required to solve a problem described within a textbook, and supplementary material needed for solving the problem can be provided by additional information that can be called up via QR-codes on mobile devices (e.g., animations, videos etc. enriching the textbook). But teacher-centered approaches to instruction like direct instruction (Stockard, Wood, Coughlin, & Rasplica Khoury, 2018) might also be appropriate for the design of AR learning environments, where the AR can guide the learner systematically through the content in order to support accomplishment of learning objectives (e.g., a pedagogical agent explaining learning material in the real world environment).

The third aspect to be considered in the design of AR learning environments is the level of enrichment provided by the augmentation. This aspect refers to the degree of relevance of information provided, i.e., whether the information is essential for students to proceed or not. In the latter case, the augmentation might contribute to what Herber (1998) refers to as "additum". Here, the content might be used by learners who have already accomplished the required learning objectives (i.e., the "fundamentum") in order to get supplementary information. Students might use these optional learning opportunities due to their personal interest and/or to increase their knowledge and skills beyond the basic learning objectives.

These three factors, the focus of the AR, the didactical/instructional approach, and the degree of enrichment are not disjunctive, but rather depend on the decisions made when designing a learning environment (see Figure 2).

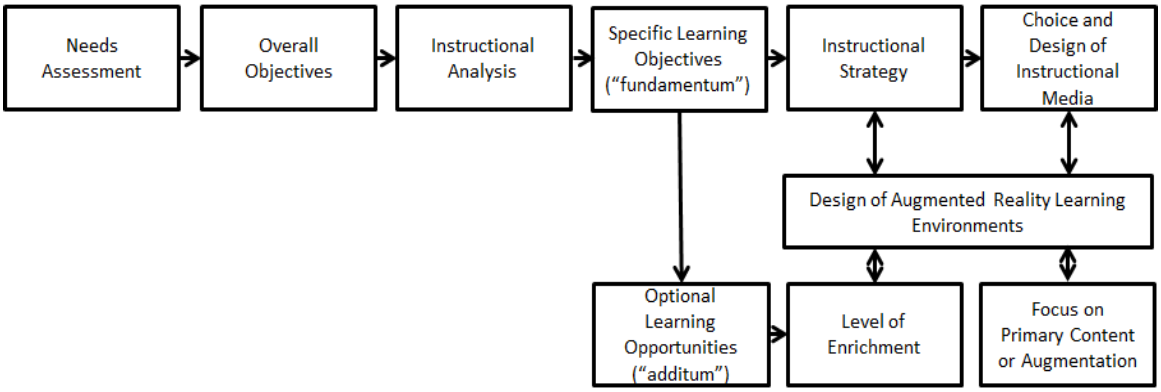


**Figure 2.** instructional design process for implementing augmented reality learning environments.

The model illustrated in Figure 2 suggests the ID process determines the basic decision whether educational use of AR is appropriate or not. The basic factor that determines the use of AR is the choice of an appropriate Instructional Strategy.

## 5. CONCLUSIONS

AR is a relative new technology within educational contexts that can support learning processes, for teachers as well as students. Before teachers can adopt AR applications effectively, some considerations need to be made. First, in teacher education AR can play a constructive role in different areas of study, but always in accordance with the premise of TPCK. Teaching trainees how AR elements can technically be created is not enough to design meaningful learning environments. Teachers have to have a feel of how AR works and how it can support the learning experience. With this in mind, they can create subject-specific learning environments and decide which pedagogical approach fits it best. Second, technology-enhanced learning should be prepared with a clear focus on learning goals. According to the model presented in this paper, an ID approach can help here. The model combines the technological (TK, here regarding AR) with the didactical/pedagogical (CK and PK) perspective and extends it with a third, the level of enrichment. This last aspect may be important for all teachers, as AR can encourage all learners to progress from their personal fundamentum to their personal additum.

Thirdly, in order for teachers to be able to actually use their AR-enhanced learning environments in class, schools must create appropriate framework conditions. This includes openness to new learning approaches such as learner-centred learning, collaboration among colleagues to create such learning environments together, and also technical prerequisites that will make the use of innovative technologies such as AR as easy as the use of traditional learning materials in the future.

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