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HAUPTBEITRÄGE - THEMENTEIL

Augmented reality for constructivist learning at work: current perspectives and future applications

Rabea Bödding[1] · Dominik Bentler[1] · Günter W. Maier[1]

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Abstract
This manuscript for the journal Gruppe. Interaktion. Organisation. (GIO) addresses the use of a new and very promising technology for work-related learning, Augmented Reality. New technological solutions have and continue to impact work in different areas, one of which is work-related learning. While Augmented Reality has been subject to numerous studies in the context of work and work training, there is a need for more detailed discussion of its relation to the theoretical foundations of learning and the therein based implications for designing and testing learning environments in Augmented Reality. For this purpose, our paper first reviews current perspectives on Augmented Reality and its value for work-related learning, before introducing and examining the concept of Instructional Design Methods. These are abstract mechanisms that can be used to support training using Augmented Reality based on expert performance. Through thorough discussion of these methods, we pose new perspectives on their application for future research and practical application.

Keywords Augmented Reality · Mixed Reality · Work-Related Learning · Constructivism · Instructional Design Methods

Augmented Reality für konstruktivistisches Lernen bei der Arbeit: Aktuelle Perspektiven und zukünftige Anwendungen

Zusammenfassung
Dieses Manuskript für die Zeitschrift Gruppe. Interaktion. Organisation. (GIO) befasst sich mit dem Einsatz einer neuen und vielversprechenden Technologie für das arbeitsbezogene Lernen, der Augmented Reality. Neue technologische Lösungen haben bereits verschiedene Aspekte der Arbeit, darunter das arbeitsbezogene Lernen, beeinflusst und werden dies auch in Zukunft tun. Obgleich Augmented Reality bereits das Forschungsthema zahlreicher Studien im Kontext von Arbeit und Trainings war, sollten die Zusammenhänge zwischen Augmented Reality und lerntheoretischen Grundlagen sowie die sich daraus ergebenden Auswirkungen auf dessen Gestaltung und Anwendung detaillierter diskutiert werden. Zu diesem Zweck werden in diesem Manuskript zunächst aktuelle Sichtweisen auf Augmented Reality und ihre Relevanz für die Förderung arbeitsbezogenen Lernens erwogen, bevor das Konzept der Instructional Design Methods vorgestellt und geprüft wird. Die Instructional Design Methods sind abstrakte Mechanismen, die zur Unterstützung von Trainings mit Augmented Reality genutzt werden können. Durch eine gründliche Diskussion dieser Methoden eröffnen wir neue Perspektiven für ihre Anwendung in der zukünftigen Forschung und in der praktischen Anwendung.

Schlüsselwörter Augmented Reality · Mixed Reality · Arbeitsbezogenes Lernen · Konstruktivismus · Instructional Design Methods

Numerous companies are examining the use of digital technologies to optimize internal company processes and support employees (Foullois et al. 2021). While at the beginning of the 2010s employee representatives understood the term Industry 4.0 as a synonym for job cuts, the perception and evaluation of digital technologies has changed in recent

✉ Rabea Bödding
rabea.boedding@uni-bielefeld.de

[1] Department of Psychology, Bielefeld University, Universitätsstraße 25, 33615 Bielefeld, Germany

years. Most of these technologies are still far from completely replacing the skills of employees, as they sometimes make jobs easier and sometimes more demanding (Mlekus and Maier 2020). However, most often these technologies offer immense potential in assisting and empowering employees (Paruzel et al. 2020). For this reason, companies are currently looking for promising applications for digital technologies (Gabriel et al. 2021), like the use of Augmented Reality (AR) for a variety of assisting applications, for instance in assembly or logistics tasks. Further, AR for work-related learning in companies has already been repeatedly examined. In particular, AR technologies seem promising for use in technical training, since a parallel processing of real workpieces can be supported by auditory, visual, and haptic information. Especially in the field of training, AR offers not just assistance, but the possibility to impart job-specific knowledge (Funk et al. 2017). Trainees can thus work on the respective training content independently of time and the trainers are aided by using digital assistance. In heterogeneous disciplines such as industrial engineering, informatics as well as psychology the use of AR in training has been examined. Just as heterogeneous as the disciplines involved, there are different perspectives in this field of research (Bansmann et al. 2019; Bentler et al. 2022). There is however a need to discuss the connection of learning theories and AR for work-related learning more closely to aid both organization of already published research and to promote future research. This paper therefore reviews current perspectives on AR and learning theories before discussing resulting instructional methods, which contribute to future research by posing possible research questions.

1 Augmented reality

AR is commonly defined through the discussion of the reality-virtuality continuum proposed by Milgram and Kishino (1994). On the continuum, (completely) real and (completely) virtual environments make up the opposite ends of the spectrum, while everything in between compromises the Mixed Reality (MR). The MR space in turn ranges from Augmented Reality (AR) to Augmented Virtuality (AV). AV describes a primarily virtual environment which includes some aspects of the real world, and also encompasses conventional Virtual Reality (VR), which usually visually replaces the real with a virtual environment. In contrast, AR is defined as an “otherwise real environment [which] is ‘augmented’ by means of virtual [...] objects” (p. 1324). The distinguishing characteristic of AR is therefore the role of the real environment. Although Milgram and Kishino’s framework is probably the most common approach to differentiate MR technologies, it has not gone uncriticized (Skarbez et al. 2021): Similarly to other approaches, like Hugues et al. (2011) or Normand et al. (2012), it focuses on the differentiation of broad categories of technologies but does not provide a sufficient basis for the practical design or research of AR.

Table 1 Overview of Frameworks on AR

Authors	Aspects of AR Considered	Role for Work-Related Learning Research
Motejlek & Alpay (2021)	Requirements of design, physical devices, the interface and the implementation of the technology, e.g., if the user interacts with the system through gestures or controllers	Enables overview of categories that need to be considered when developing AR/VR experience for learning (e.g., educational purpose such as training or observing, type of gamification)
Hertel et al. (2021)	The tasks that can be carried out through the interaction, such as highlighting aspects of the environment, and the modalities used to achieve the interaction, for instance through tactile means	Different interaction techniques may be more or less suitable for the intended purpose, such as learning in AR; this overview provides a basis for the identification of research gaps and subsequent testing of different techniques
Zollmann et al. (2021)	Aspects ranging from visualization, data visibility, integration of environmental cues or the composition of real and virtual input	Challenging visualizations, i.e., due to the way virtual objects in AR are displayed and their interactions with the environment, may hinder perception of and interaction with the content, and thus inhibit work-related learning
Merenda et al. (2018)	Interface design depending on whether the virtual elements are fixed to the screen or fixed to elements of the real world and if they are statically fixed to a specific location or animated and able to translate through their environment	While not initially related to learning environments, where learning content or instructions are fixed in AR may impact learning by reducing cognitive distance between physical and virtual elements
Müller and Dauenhauer (2016)	Visualization in terms of information linking, the connection of an anchor in the physical world with the information object, which provides the digital information through the orientation of the information in space, the design of the visual connection through the Gestalt principles and the addition of further context to the visualization	Provides insights in how content should be presented in AR to ease the perception of relevant information, which in turn may impact learning outcomes by lowering the required workload in the AR environment

However, detailed frameworks of AR supply the basis for many applications of the technology, including entertainment and gaming, as well as different areas of work and education (Nizam et al. 2018). By considering distinct features of AR, the field may gain insights into how AR supports work-related learning (see Table 1). However, these frameworks are focused primarily on technological implementations, which often leads to a technology- rather than a learning-centered approach to implementing and studying AR (Buchner and Kerres 2023). For the context of work-related learning, this is further reflected in the frameworks' removal from the learning contents that are transported or scaffolded through AR and, more generally, their independence of learning theory overall. In the following sections we will therefore briefly examine the current application of AR for work-related learning and reflect how theories of learning support this application.

1.1 Current applications of augmented reality for work-related learning

In recent years AR has increasingly been applied in many workplaces, from medicine and retail to different industrial areas, including assembly, maintenance, and logistics, especially in an assisting role. In a literature review, Egger and Masood (2020) found that the use of AR was associated with improved performance in an industrial context, such as time savings or accuracy, as the user can be guided through the processes. Overall, AR has been recognized as an important technology to assist in working tasks (Nizam et al. 2018). In the face of changing demands in the workplace however, the use of these technologies should be considered beyond simply assisting, but rather aiding the human-centered development of work. Continuous training is necessary for workers to adapt successfully in the ever-changing workplace (Cascio and Montealegre 2016) and the technical possibilities for using AR for trainings at work have been discussed at length (Limbu et al. 2018a).

A first meta-analysis in the medical field found that AR trainings had a positive effect on outcomes, such as knowledge and skills (Baashar et al. 2022). Bödding et al. (2023) found, that vocational trainings using MR trainings in general and AR trainings in particular, had significant positive effects on behavioral, cognitive and affective training outcomes, though much of the primary research has focused on media comparisons (e.g., testing AR vs. textbook learning). This is echoed by Buchner and Kerres (2023), who criticize the reliance on media-comparison research: Attributing the failure or success of learning interventions to the use of an unspecified AR intervention is insufficient, as it compromises methodology (e.g., replicability) and fails to extend our knowledge on learning and instruction in AR. Therefore, results from studies that compare versions of AR are necessary, though less common. For instance, Wu et al. (2018) and Chen et al. (2020) found that when AR was designed following theoretical considerations and instructional principles (vs. not), learning outcomes were higher. For work-related learning specifically, Werrlich et al. (2018b) showed that training transfer in an AR assembly training was higher when active learning of the participants was prompted. To further comparative research *within* AR, learning theories and instructional design should be considered as the field currently does not provide sufficiently tangible guidelines on AR usage for work-related learning (Bower and Sturman 2015). The following section will therefore briefly review general learning theories before examining how AR supports work-related learning on this foundation.

1.2 Learning theory and augmented reality

To better understand the impact of AR for work-related learning, it is important to consider the theoretical background before which it is designed. The major perspectives in the field include behaviorism (learning as a behavioral change resulting from connecting specific stimuli with corresponding reactions based on classical conditioning), cognitivism (learning as information processing, i.e., thinking, understanding, and remembering, leading to a mental model encompassing one's knowledge) and constructivism (learning as the construction of mental structures through active processing of the environment and social interactions, as well as the integration of new information with prior knowledge; Maier et al. 2019; Noe 2023). While learning with AR can be understood through the lens of all these theories, constructivism especially lends itself to the application, as it requires learners to be confronted with meaningful environments, where their prior knowledge can be transferred in new situations and where they may be supported in their knowledge construction (Dunleavy and Dede 2014). From a constructivist view, AR may take a unique role as it allows users new possibilities to actively interact with a complex environment, for instance by guiding their attention, adding virtual objects not available in the real environment, or enriching it with additional information.

Though it is usually feasible to include aspects of multiple perspectives on learning to design training interventions, this article focuses on the constructivist approach for several reasons: First, it recognizes the importance of supporting learners in situation-specific knowledge construction, which is especially relevant for work-related learning (Dehnbostel 2021; Tynjälä 2009). Second, constructivist learning approaches can be supported through a wide range of methods in AR, as will be discussed in the following. Finally, this approach has been broadly adapted as the theoretical foundation for AR usage in education (Sommerauer and Müller 2018).

For work-related learning in particular it is also relevant that learning may take place in different contexts: Learning can be formal, for example highly structured in a classroom setting, or informal, making it much less structured and more controlled by the learners themselves. While formal and informal learning are usually also intentional, meaning not necessarily structured but encouraged by the organization, work-related learning can also take place incidentally, meaning ubiquitously but largely unconsciously (Maier et al. 2001). Concerning the context, the potential for AR is present in formal as well as informal learning environments, as it may be integrated in structured learning efforts or offered as a tool for self-directed learning.

1.3 Instructional design methods in augmented reality

As there are good theoretical and practical reasons to implement AR for work-related learning, this section more closely considers its realization. As is the case with all trainings, learning environments and materials should be implemented using theoretically founded instructional design, which includes the systematic design, development and delivery of the instructions required for the learning process (Frey and Fisher 2010). As discussed above, frameworks have been developed to help design and analyze AR in general, and AR for learning in particular, however, their main focus lays with the technological design choices (e.g., choice of controller) or underlying design aspects (e.g., occlusion of virtual objects). Recognizing this, Limbu et al. (2018b) set out to examine how AR is actually utilized to transport knowledge and expert performance in training programs. Through extensive literature searches

Table 2 Instructional Design Methods (adapted from Limbu et al. 2019)

IDMs	Definitions	Modality
3D Models & Animations	Assist in easy interpretation of complex models and phenomena which require high spatial processing ability	Visual
X-Ray Vision	Visualizing objects and processes that are hidden behind physical surfaces and invisible to the eye	Visual
Interactive Virtual Objects	Interactable virtual objects to practice with physical interactions relying on the 3D model and animation *(See* Fig. 4*)*	Visual (Haptic)
Augmented Mirror	Display where trainees can track their body posture	Visual
Ghost Track	Allows visualization of the whole-body movement of the expert or the earlier recording of the trainees themselves for imitation and reflection	Visual
Avatar[a]	An interactive visual representation of real or abstract persons or figures that can communicate with the user	Visual Auditive
Directed Focus	Visual pointer for relevant objects outside the visual area of the trainee	Visual
Highlight Objects of Interest	Highlighting objects of interest in the physical environment *(See* Fig. 2*)*	Visual
Augmented Paths	A virtual path augmented in the physical environment to guide motion	Visual
Cues & Clues	Single annotation, pivots which trigger solution search	Visual Auditive
Annotations	Augmented annotations added to physical objects	Visual Auditive
Object Enrichment	Virtually amplify the effect of a process to enable trainees to understand the consequences of certain events or actions in the process, which may be too subtle to notice	Visual Auditive
Contextual Information	Provide information about the process that is frequently changing but is important for performance *(See* Fig. 3*)*	Visual Auditive
Point of View Videos	Provides expert point-of-view video which may provide perspectives not available in a third person	Visual Auditive
Mobile Control	In instances where a remote expert is needed, it acts as an instant communication channel without having to divert from the workflow	Visual Auditive (Haptic)
Formative Feedback	Light weight feedback during the learning process	Visual Auditive Haptic
Summative Feedback	Feedback provided at the end of a practice session	Visual Auditive

[a] newly added IDM, see Sect. 2

Fig. 1 Example of the IDM “Highlighting Object of Interest” in the AVIKOM project. Picture used with permission

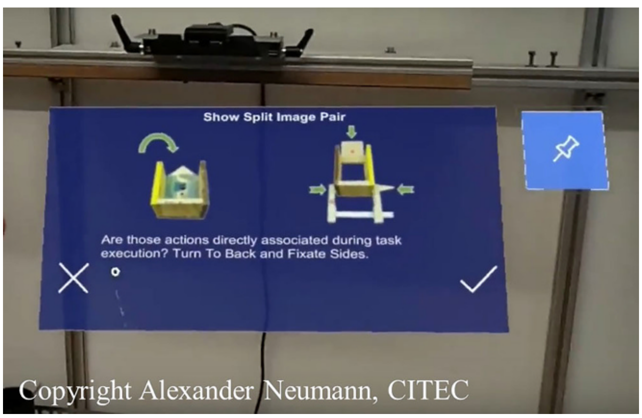

Fig. 2 Example of the IDM “Contextual Information” in the AVIKOM project. Picture used with permission

and expert interviews, the authors identified 17 AR specific IDMs (Limbu et al. 2018b, a), which they defined as “learning design patterns that leverage expert performance to support training using sensors and AR” (p. 3). IDMs are therefore design elements of AR that transport or scaffold learning content and which are independent of the domain (e.g., training in medicine or industry) and as such applicable to various training scenarios. A list of IDMs and their definitions used in this paper is provided in Table 2, while Figs. 1, 2 and 3 showcase examples of implemented IDMs.

Figure 4 showcases examples of different scenarios in which AR could be applied for work-related learning. On the one hand this highlights the diverse contexts in which work-related learning may be supported with AR, on the other hand, the examples also include different kinds of implementations of AR, which are used to support learning. For instance, learners’ exploration of learning content and knowledge construction can be supported by providing additional guidance in the environment, direction attention to important elements or adding people or objects that are not available or save in the real environment. These aspects are crucial for the implementation of AR particularly for learning in general and work-related learning in particular, as they provide the actual supporting information required and enable more comparative research in the field, replacing simple technology comparisons (Buchner and Kerres 2023). The following sections will look at these AR design elements more closely and reflect them according to the focus of their augmentation before considering how they relate to the theoretical background of learning explored above.

Fig. 3 Example of the IDM “Interactive Virtual Objects” from the Fraunhofer IEM. Picture used with permission

2 A revised perspective on IDMs for AR

In a first step, we attempted to evaluate if the proposed list of IDMs is complete and if any are redundant, as the authors themselves state that the list is not exhaustive. As detailed in Table 2, most IDMs address the visual sense, though some also integrate haptic and auditive components. As current research also addresses the augmentation of the olfactory or gustatory senses, new IDMs or extensions of existing IDMs are possible in the future of which numerous training scenarios would benefit (Normand et al. 2012). Furthermore, conventional perceptions of AR focus exclusively on the exteroceptive senses, which react to outside stimuli, while disregarding the interoceptive senses, which provide information about the body’s internal state (Skarbez et al. 2021). The internal state of the body, such as one’s own perception of an elevated heart rate or sense of balance are important aspects of learning, especially in safety trainings. In the future, AR technologies may not only address human senses but circumvent this transition and address the human brain more directly through e.g., human-brain interfaces. On the one hand, both the implicit and explicit control of the augmentation through brain activity are being explored (e.g., Putze et al. 2020), which may eliminate the need for controllers to interact with the digital system.

Fig. 4 Example scenarios for AR-based trainings at work

Example 1: AR-Based Training for Assembly Workers

A company introduces a new product which requires assembly workers to use new machinery and materials, requiring additional training. After assessing the workers state of knowledge and providing basic background information on the new material in the classroom, they can start to train directly on the machine using AR glasses. Through the AR glasses they are guided to the new assembly steps and their attention is directed to important aspects of their environment. As the workers progresses through the assembly steps, mistakes can be highlighted to provide immediate feedback.

→ AR: guidance, direction of attention, feedback

→ Formal & intentional learning

Example 2: AR-based Safety Training

Many companies require their employees to partake in safety training, especially where new equipment is concerned. Using AR, virtual objects can be introduced into the real world to amplify hazardous scenarious and showcase potential consequences. By providing contextual information in the safety-relevant environment, employees can learn about safe working habits. This approach may also lessen the workload of trainers, as employees can use the AR-based safety training independently and guide their own learning process.

→ AR: direction of attention, showing dangerous situations

→ Informal & intentional learning

Example 3: AR-based Training for Surgery

Many hospitals, do not have the neccessary expertiece to perform highly specialized interventions. In this case an AR-based system allows remote experts to view the surgery in real-time, advice local surgeons accordingly and even digitally highlight points of interest in the field of vision of the user. The local surgeon can learn new skills in a highly specific and risky situation through expert guidance. It can further be used to provide surgeons with relevant information during a proceudre, such as medical imaging and hospital guidelines for operating standards.

→ AR: remote learning, highlight important elements in the environment, timely information

→ Informal & incidential learning

On the other hand, the afferent delivery of sensations to the brain (e.g., Flesher et al. 2021), for instance the triggering of tactile perception of virtual objects directly in the brain, could provide new avenues for AR in the future. As the current state of AR development focuses on the visual, auditive and haptic senses, we have decided against exploring possible IDMs based on other examined senses at this point but urge to consider them more closely as the technology develops.

Next, we looked toward other technologies to see if any commonly used methods may be implemented in AR but have not been included by Limbu et al. (2019). In many learning, but also gaming environments, e.g., on PC or in VR, avatars are frequently used to either represent the user themselves or as a partner in an interaction (Greenwald et al. 2017; Afifi et al. 2020; Yoon et al. 2019). As avatars were not included in the original list of AR IDMs, we propose avatars as an added IDM as it may take the place of a teacher or partner during a learning task (see Fig. 5 for an example) and added it to Table 2. Orientated at previous research, we define the IDM *Avatars* as an interactive visual representation of real or abstract figures that can communicate with the user. They may guide learning or model various behaviors as a teacher would in classical instructional design and thus even encompass features of other IDMs. This interactivity and guidance distinguish avatars from the Ghost Track IDM, which focuses on the visualization and subsequent reproduction of movements. Beyond aspects of

Fig. 5 Example scenario for the use of an avatar in AR trainings. Illustration created via canva.com

Example: Implementation of an Avatar in AR Training

A company bought a new machine for packaging their products and is training their employees on updated features of the new device using AR. The avatar may explain the setup and new features of the machine and prompt the user to conduct certain tasks or examine parts of the machine more closely. The trainee may interact with the avatar, asking for additional information or repeated explanations. The avatar may also model certain behaviors for the trainee.

(visual) avatar design and rendering (e.g., stylized, or realistic, shown body parts), there are several aspects of the interaction (e.g., walking vs. non-walking, hand interaction) and the communication (e.g., bi-directional vs. uni-directional communication) that may be more or less suitable for a certain learning situation (Weidner et al. 2023). As of yet, there are few applied examples of Avatars in VR trainings at work and even fewer for AR: For example, Werrlich et al. (2018a) implemented an abstract robot-style avatar, which provided the trainees with auditory feedback and animations using a gamification approach in an assembly task, which resulted in better learning outcomes compared to a non-AR control group. Weidner et al. (2023) more generally reviewed findings of Avatar usage in VR and AR, proposing preliminary guidelines for their implementation, which indicate that higher visual fidelity of the avatar is desirable for (learning) outcomes.

We further discussed the redundancy of any proposed IDMs. We found that three kinds of feedback were included: haptic, formative and summative feedback. While formative and summative feedback were deemed sufficiently distinct due to their scope and time of the interaction, this was not the case for haptic feedback. Haptic feedback is provided during the interaction with the AR system and provides feedback on ongoing learning tasks. As the definition of formative feedback also includes the haptic modality, we decided to exclude the haptic feedback IDM and suggest it is already part of the formative feedback IDM.

2.1 Relating IDMs with learning theory

In an effort to integrate AR more directly with learning theory, Limbu et al. (2018b) assigned the IDMs to the separate phases of the Four Component Instructional Design model (4C/ID; van Merriënboer et al. 2002). The 4C/ID model can be used to design learning environments for complex skills, marked by i.e., the integration of knowledge, skills, and attitudes. Within the framework of these complex task, subtasks are identified and described through the four components seen in Fig. 6: the learning task (complex tasks based on real work tasks), supportive information (additional information that helps learners to complete the learning task), procedural information (specific, timely information for routine tasks) and part-task practice (extended, repeated practice of parts of the whole learning task).

This approach has a somewhat instructivist focus (van Merriënboer et al. 2002), which may hinder knowledge construction from a constructivist perspective, for instance though reduced possibilities for exploration of the learning environment. This is accompanied by a strong focus on the learning task rather than the environment in the theory, while AR provides unique possibilities to scaffold both. While connection of technological possibilities with learning theory is an important objective, the current developmental state of AR and relatively unstructured research findings in this area may not provide a sufficient basis for this assignment of IDMs to specific parts of the 4C/ID and underlines the need for more comparative research within the AR space. This is highlighted throughout the development of the framework, as several of the identified IDMs have been assigned to different phases of the 4C/ID in different papers (Limbu et al. 2019, 2018b, a). Furthermore, it is unclear if any specific IDM can only be applied to one of the phases of the model as proposed, rather than to multiple phases.

2.2 A different approach to IDMs

For these reasons, we propose a different approach to organize the identified IDMs in line with learning theoretical background, which is more suitable than the top-down approach described earlier. For this purpose, we followed an inductive, bottom-up approach to cluster the IDMs according to their similarities (Kuczynski and Daly 2003). This simplifies the facilitation of the IDMs regarding technology and learning theory, providing a more accessible basis

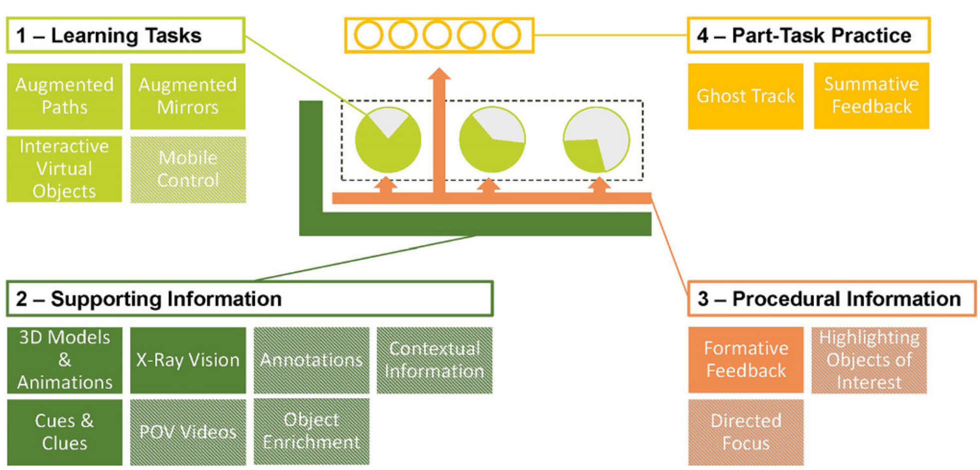

Fig. 6 The 4C/ID framework adapted from van Merriënboer et al. (2002) and the assignment of the IDMs to the different phases based on Limbu et al. (2018b). Striped boxes indicate IDMs that have been sorted in different phases of the 4C/ID

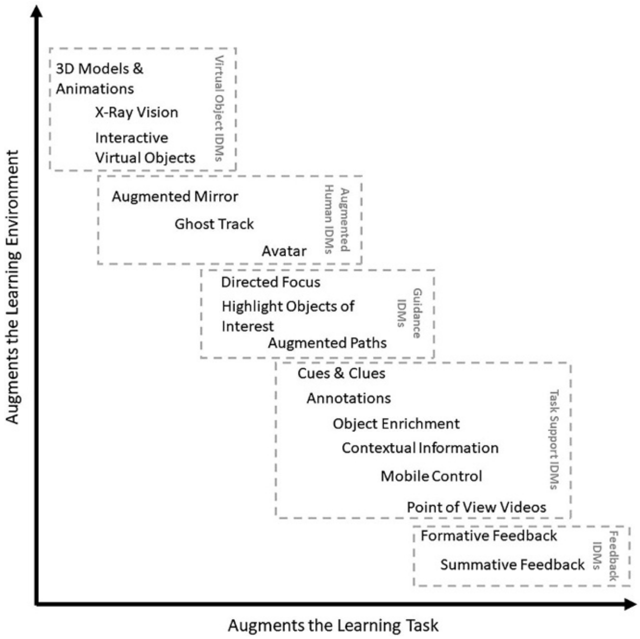

Fig. 7 Approximate location of IDMs on the proposed dimensions with the identified categorization of IDMs

for comparative research and discussion. We propose that the IDMs differentiate in the degrees to which they augment the experience of the learner by augmenting a) the learning task or b) the learning environment. While, generally, IDMs are focused on augmenting the overall learning experience of the learner, some of the IDMs augment a specific learning task that learners need to solve (e.g., providing instructions through contextual information or receiving summative feedback), which may take place somewhat or even completely independent of the environment in which the task takes place. On the other hand, some IDMs augment the environment with little explicit connection to a specific learning task (e.g., adding virtual objects or movements to the real environment), while many also combine both kinds of augmentations (e.g., cues connect to the real environment but directly facilitate the learning task). Figure 7 visually displays the proposed dimensions and provides approximate locations of the IDMs on the axes according to their definitions.

Along these axes we were able to further cluster similar IDMs in five main categories: virtual objects, augmented body, guidance, task support, and feedback. The *Virtual Object IDMs* augment reality by presenting virtual objects which may be integrated into the environment to different degrees, while interactivity is added for more complex augmentations. They primarily augment the environment but provide little augmentations to a learning task that needs to be completed. *Guidance IDMs* guide the learner toward information or relevant aspects of the physical environment by directing their attention or movements, however, there is a clearer relationship to the learning task, as the information in the environment is relevant for this specific task. In contrast, *Augmented Body IDMs* augment the learner's environment through the presentation of and interaction with another real or virtual person or an augmentation of oneself. They, however, do not solely augment the environment, but also give increasing space for augmenting the task execution. The *Task Support IDMs* range from low-level annotations over more complex augmentations of the learning task to live assistance by a teacher, aiming to support the completion of the learning task. Here, the AR visualizations are clearly augmenting the task, and the environment plays a much more secondary role, as many of these IDMs are no longer integrated in the real environment. The final category, *the Feedback IDMs*, clusters those IDMs that provide feedback during or after completion of the task. Especially summative feedback is almost completely removed from augmenting the environment but is strongly focused on augmenting the learning task.

The identified IDMs and categories can and should be used to support learning from a constructivist perspective by providing instructional scaffolding to guide learners in their interaction with the environment. Frey and Fisher (2010) identified several instructional scaffolds that aid in guiding learning: prompting (meta-)cognitive work, cueing students' attention and providing direct explanations and modeling. Several IDMs may prompt cognitive and metacognitive work, especially those focused on augmenting the task to be completed, by providing background and process knowledge. Other IDMs, such as the Guidance IDMs or most Task Support IDMs, are clearly suitable to cue student's attention by redirecting trainee's focus to essential elements of their learning experience. Finally, instructional scaffolds like Virtual Object or Augmented Human IDMs can be used to supply direct explanations and modeling when the other methods fail. Yet, it is important to note that the IDMs may appear as different scaffolds or as more than one form of scaffold at any given time, depending on the task, implemented technology and target audience. The Feedback IDMs in particular may be a relevant addition to any applied IDM.

The connection to the formality and intentionality of work-related learning also becomes clearer when considering IDMs this way. Formal learning environments, for instance, are often removed from the environments and key characteristics (e.g., machines, patients) that are central to the learning goals. Here, it may be more sensible to focus on augmenting the environment, for instance with Virtual Object or Augmented Human IDMs. More informal learning environments are often already directly connected to the real working environment but may benefit from more opportunities to scaffold learning in these situations, e.g., through Task Support or Feedback IDMs. There are also additional opportunities to implement IDMs for incidental learning in situations where AR is already deployed for purposes that are not primarily educational (e.g., assembly assistance), by considering these issues during the implementation of such systems.

This approach also highlights the strengths of AR for work-related learning. While some IDMs, like Point-of-View (PoV) videos or summative feedback also apply to more conventional technologies, such as desktop-centered E-Learning, others, like Contextual Information or Highlighting Objects of Interest are specific to the AR space, as both the task and the environment are augmented. Similarly, some IDMs, such as Interactive Virtual Objects, are not only applicable in AR but also essential aspects of VR. The proposed IDMs provide an intriguing perspective on AR design and may supply a new basis to explain the mechanisms making AR a useful tool for work-related learning.

3 Implications for research and practice

Considering work-related learning and IDMs in this way opens further avenues of research and will help the field move away from simple media-comparison studies. For instance, there is little indication for the effectiveness of specific IDMs, neither in comparison to each other, nor in their application to specific types of tasks or how different IDMs may be applied together. However, the here presented categorization of the IDMs may provide a structural basis for the exploration of these questions. In a first step, previously conducted research should be reviewed to reveal how IDMs have performed. On that basis, the IDMs may then be experimentally tested against each other to answer open research questions regarding the use of AR for work-related learning:

- Which IDMs are suitable for different types of learning tasks?
- How effective is training using AR in the long term (e.g., after 1 week or 1 month)? Does this differ for implemented IDMs and tasks?
- How does AR and the implementation of specific IDMs support deeper processing of the learning objectives?
- Does the implementation of AR in general and certain IDMs in particular have negative effects on the health of learners (e.g., in the case of simulator sickness or as added stressors)?
- How does the implementation of AR for work-related learning affect the tasks of the trainers?

When considering the design of an AR application for work-related learning, the proposed categorization may help practitioners to choose the appropriate kind of IDM to support learners active learning and integration of prior knowledge to construct their own knowledge representations. Following an analysis of the learning goals, the required steps, provided environment and technology, and the requirements of the learners, practitioners may consider if the augmentation of the task is more important (e.g., if prior knowledge is lower) or if the augmentation of the environment is more appropriate (e.g., if independent exploration of the learning content is desirable). Within the categories of IDMs, suitable options may then be obtained regarding the overall requirements of the individual learning application (e.g., the choice between different guidance IDMs or their combination).

In this process other elements of the AR space also need to be considered: For instance, the careful consideration of hard- and software solutions, or the finalization of design decisions are important aspects beyond the implementation of the IDMs (see Table 1 for the overview). Beyond specific task and design related research questions, the technological and organizational context needs to be considered when AR is implemented to support work-related learning. On the other hand, stakeholders in the organization may hold resistance against the use of AR in general, which an appropriate change management can address and dismantle, though for learning applications in particular, it may be beneficial to go further and implement change management interventions that actively focus on improving learning environments (Mlekus et al. 2022; Schlicher et al. 2022; Paruzel et al. 2020).

Overall, we can note that AR has the possibility to support work-related learning in new ways and transform the learning experience in organizations. The identified IDMs showcase different options on how AR can be applied for this purpose in practice and provides first structures to choose between different IDMs, which should be considered in the practical design of AR for work-related learning purposes. This article also underlines a warning made by previous researchers such as Bower and Sturman (2015), which is that pedagogy cannot be neglected if AR is implemented for education and that AR needs to be embedded within larger systems to achieve its full potential. Within these systems relevant information on the learning process and the organization can be collected and instructional scaffolding can be adjusted accordingly, as is being explored in current research projects (Bödding et al. 2022; Oestreich et al. 2021). Concluding, we therefore urge to recognize the need for multidisciplinary teams to facilitate the integration of technology and pedagogy in the larger organizational and research context.

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Rabea Bödding is a research assistant at the department of Work and Organizational Psychology at Bielefeld University. Her research interests are the design of technologies to support and enhance learning and work design and competency requirements in digitalized workplaces.

Prof. Dr. Günter W. Maier is a professor of Work and Organizational Psychology at Bielefeld University. His research interests include justice in human-machine interactions, qualification requirements, leadership and work design in the digital transformation, and creativity.

Dominik Bentler is a research assistant at the department of Work and Organizational Psychology at Bielefeld University. His research interests are interventions to improve employee green behavior and the effects of digital transformation in the work context.