# Accessible Augmented Reality Learning Experience Journey across DHBW - A Case Study

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**Abstract.** While Augmented Reality (AR) can transform education, its adoption is often limited by gaps in digital competence and accessibility. This case study evaluates the "Accessible AR Learning Experience Journey" at DHBW to identify how institutions can transition from exploratory pilots to inclusive, scalable AR integration.

An exploratory qualitative case study design was employed. Evidence was collected from workshops, pilot implementations, institutional documentation, stakeholder reflections, and observational logs. The analysis adopts a four-phase maturity framework, i.e., Starter, All-Rounder, Specialist, and Expert, as an analytical lens to examine institutional capability development across diverse delivery formats: face-to-face, online and hybrid settings.

The findings document a progression from exploratory AR demonstrations to the implementation of inclusive and pedagogically integrated AR learning scenarios. Key outcomes include the development of accessibility-aware AR authoring tools, co-designed learning scenarios addressing life skills education, and the integration of AR across vocational and academic contexts. The analysis also identifies critical enablers and barriers to adoption, notably stakeholder collaboration, organizational support, and scalable technological infrastructures.

The study demonstrates that sustained institutional commitment, iterative development, and inclusive design practices are essential for embedding AR as a meaningful and accessible learning technology. The proposed maturity framework offers transferable insights for higher education institutions seeking to implement AR in an inclusive and sustainable manner.

**Keywords:** Augmented Reality, Accessibility, Higher Education, Qualitative Case Study, Institutional Adoption

## 1 Introduction

Augmented Reality (AR) has rapidly evolved into a pervasive technology that offers transformative possibilities for enhancing learning experiences across various educational disciplines [1]. Its capacity to overlay digital content onto the physical environment facilitates immersive, experiential learning across diverse domains, including academia, manufacturing, Healthcare and Medicine, Retail and E-commerce, and


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Hospitality and Tourism [2]. Despite its growing prevalence and demonstrated educational potential, substantial challenges remain regarding user awareness, digital competencies and accessibility [3, 4]. These limitations make it harder for everyone to take part in and benefit equally from AR-based educational interventions. This is especially true for learners and educators with disabilities or limited technological proficiency [5].

In response, Baden-Württemberg Cooperative State University (DHBW) has led to the establishment and ongoing development of various AR initiatives across multiple locations. Among these efforts, the AR Learning Authoring and Accessibility (AuReLiA) research laboratory at DHBW Heidenheim, which is collaboratively hosted with other DHBW locations, stands out. The lab integrates open-source AR authoring tools, open educational resources, UX and accessibility design to enable inclusive AR learning opportunities. This case study presents the structured AR experience journey undertaken by DHBW. It documents activities across distinct maturity phases: Starter, Allrounder, Specialist, and Expert. Each maturity phase encompasses a diverse set of AR experiences delivered through face-to-face, hybrid, and online formats, reflecting a strategic progression towards deeper integration and higher complexity.

The Starter phase helps participants learn basic AR concepts and gain their first experiences, focusing on building awareness and essential skills. In the Allrounder phase, participants work with AR in real scenarios, such as industry visits and interdisciplinary projects, to apply what they have learned and broaden their understanding. The Specialist phase encourages deeper involvement, with a focus on working closely with external partners and using AR in specific, intensive situations. The Expert phase brings everything together, with advanced projects that include mature authoring, improved accessibility, and applications tailored to particular fields.

This paper looks at each phase to address an ongoing problem: even though AR tools are more common, many people in higher education still lack awareness and access. This limits how widely AR can be used. By sharing detailed examples from DHBW, the study offers practical guidelines and insights for institutions that want to make AR more accessible and sustainable.

## 2 Literature Review

AR has greatly affected education, providing multimodal, interactive experiences that improve student involvement, motivation and learning effectiveness [3, 6]. Reviews usually find that AR improves learning in higher education, especially for collaborative work and self-guided exploration [3, 7]. However, research also points out that these benefits are not always consistent and often appear only in specific cases, rather than as part of ongoing institutional practice [8].

Accessibility has arisen as a vital but insufficiently addressed dimension of AR-based learning. Research shows that AR applications incorporating accessibility features can support learners with varied requirements, including students with hearing and vision impairments [9-11]. However, accessibility is frequently treated as a post hoc accommodation rather than an integral design principle. Scholars therefore emphasize the need to embed accessibility considerations already at the authoring stage to ensure inclusive participation [12].

A persistent challenge in educational AR adoption concerns content creation [13]. The development of high-quality AR learning materials often requires technical expertise that many educators lack [14]. Existing AR authoring tools frequently fail to meet educators' needs for ease of use, intuitive interfaces, and accessibility support [15], limiting both pedagogical integration and inclusive practice. Consequently, prior research advocates user-centered and participatory design approaches that involve educators and explicitly integrate accessibility features to improve adoption and usability [4, 12].

Recent literature further highlights that successful AR integration depends on a strong pedagogical foundation. While general technology integration frameworks such as Technological Pedagogical Content Knowledge (TPACK) and Substitution, Augmentation, Modification, Redefinition (SAMR) offer useful perspectives on educational technology adoption, they struggle to capture the spatial, embodied, and immersive affordances of AR environments [16, 17]. In response, specialised models such as the Cognitive Affective Model of Immersive Learning (CAMIL) explicitly link immersive affordances, such as presence and interactivity, to cognitive and affective processes that support factual, conceptual, and procedural learning outcomes [17]. In parallel, recent extensions of the DigCompEdu framework for extended reality (XR) emphasize the need for new educator competencies, including spatial awareness, 3D content creation, and the management of real-time data in immersive environments [17]. These perspectives underscore that AR effectiveness depends not only on technical sophistication but also on alignment with learning objectives, learner needs, and curriculum design [16, 18].

From an institutional perspective, technology adoption models such as Diffusion of Innovations and the Technology Acceptance Model (TAM) provide insights into factors influencing AR uptake, including perceived usefulness, ease of use, compatibility, and trialability [19-22]. Complementary AR/VR maturity models, often inspired by the Capability Maturity Model Integration (CMMI), describe staged progressions from experimentation to optimized implementation [23, 24]. Empirical evidence, however, indicates that many institutions remain at early maturity stages due to technological constraints, organizational resistance, and limited user acceptance [21, 25]. Notably, these models rarely account for how pedagogical alignment and accessibility practices evolve as part of institutional capability development.

Empirical studies from higher education and vocational training illustrate AR's pedagogical potential when aligned with curricular goals and contextual needs. Applications at Saarland University and the University of Stuttgart demonstrate improved conceptual understanding through AR-supported visualization of abstract phenomena [26, 27]. In vocational and technical education, AR has been used to address safety, resource, and training constraints, e.g., through Mixed-Reality-in-the-Loop Simulation (MRiLS) [28] and immersive professional training environments [29, 30]. Across these contexts, success is associated with curriculum alignment, usability, stakeholder involvement, and iterative refinement [20].

Synthesizing this literature, prior work identifies recurring success factors for AR in education, including user engagement, learning effectiveness, accessibility and inclusivity, usability, technological integration, collaboration, and sustainability [31-36]. Rather than treating these factors as isolated evaluation metrics, recent research increasingly conceptualizes them as interdependent institutional capabilities that develop over time [37, 38]. This perspective informs the present study, which examines how these capabilities evolve across phases of AR adoption and how accessibility becomes embedded as a core dimension of institutional maturity within the DHBW AR learning experience journey.

# 3 Methodology

## 3.1 Research Design

This study adopts an exploratory qualitative case study design, which is well-suited to investigating complex, context-dependent phenomena in which the boundaries between the phenomenon and its context are not clearly defined [39]. The primary aim is to examine institutional capability development for accessible AR in higher education, rather than to evaluate learning outcomes or technological effectiveness. The focus is therefore process-oriented, aligning with interpretive and design-informed research traditions in educational technology [40]. The four-stage journey (Starter, All-Rounder, Specialist, Expert) is employed as an analytic lens to interpret the maturation of institutional practices and competencies.

The case is bound to AR initiatives conducted at DHBW across multiple institutional contexts, including teaching, professional development, pilot deployments, and collaborative projects. The study is longitudinal, capturing developments over successive academic cycles. The journey phases do not represent discrete cohorts but iterative and cumulative stages of organizational learning, consistent with process models of technology adoption and capability growth [19]. Empirical material was retrospectively organized into phases based on observable shifts in pedagogical integration, accessibility awareness, stakeholder coordination, and infrastructural alignment.

## 3.2 Data sources

Multiple qualitative data sources were used to enable methodological triangulation [41]. These include:

1. Artefacts from workshops and training sessions (materials, tasks, feedback notes);
2. Documentation from pilot AR implementations (scenario descriptions, deployment notes, reflective summaries);
3. Institutional documents such as internal reports, project notes, and guidelines;
4. Stakeholder reflections collected through structured and semi-structured feedback formats; and
5. Observational and reflective logs maintained by the authors throughout development and deployment activities.

### 3.3 Participants and Sampling

Participants comprised a heterogeneous group of stakeholders typically involved in educational technology initiatives, including educators, educational technologists, AR developers, institutional coordinators, external partners, and students. Participant recruitment followed a combined purposive and convenience sampling strategy. Purposive sampling was used to ensure inclusion of information-rich participants with direct involvement in AR activities across phases, consistent with qualitative case study practice aimed at maximizing relevance to the phenomenon under investigation [42, 43]. In addition, convenience sampling was applied in selected events (e.g., open demonstrations, workshops, and collaborations), where participation was determined by accessibility, availability, and practical constraints typical of field-based educational research [44, 45]. This combined approach is appropriate when the study aims to capture both (i) key stakeholder perspectives central to institutional capability development and (ii) naturally occurring participation in authentic institutional settings, thereby supporting ecological validity while maintaining analytic focus [42, 44, 45].

### 3.4 Analytical Approach

The data analysis used a thematic analysis approach [46] along with pattern matching to the proposed maturity framework [39]. First, qualitative material was coded to find recurring themes about pedagogical practices, accessibility, stakeholder roles and institutional support. Next, these themes were mapped to the journey phases to identify key capability patterns and signs of transition. We used data triangulation to maintain trustworthiness and reliability [47].

## 4 Case Details: Institutional AR Capability Development at DHBW

The AR experience journey at DHBW is structured into four analytically distinct maturity phases: Starter, All-Rounder, Specialist, and Expert. These phases represent increasing levels of institutional capability in adopting, integrating, and scaling accessible AR learning practices. Activities were delivered through face-to-face, hybrid, and online formats in all phases. These activities were selected to balance immersive engagement, flexibility, and accessibility. Face-to-face formats supported hands-on interaction and immediate feedback [48], online formats enabled flexible and self-paced learning [49, 50], and hybrid formats combined these advantages to promote learner autonomy and collaboration [51]. Rather than serving solely as chronological stages, the phases reflect qualitative shifts in capability characteristics, stakeholder roles, accessibility practices, and institutional embedding (**Table 1**).

**Table 1.** Comparative Overview of AR Capability Maturity Phases at DHBW

| Phase | Capability Characteristics | Stakeholder Roles | Accessibility Practices | Institutional Embedding |
|---|---|---|---|---|
| **Starter** | Awareness, basic AR competence | Observers, participants | Implicit, format-driven | Demonstrative, ad hoc |
| **All-Rounder** | Applied exploration, technical skills | Students as developers; industry as exemplars | Emerging, contextual | Networked, cross-institutional |
| **Specialist** | Inclusive, domain-specific implementation | Co-designers, researchers, target users | Explicit, user-centered | Research-embedded, curricular pilots |
| **Expert** | Consolidation, scaling, dissemination | Faculty communities, leadership | Normative, systemic | Strategic, sustained, transferable |

### 4.1 Starter Phase: Awareness and Initial Capability Formation

**Capability characteristics.** The Starter phase represents the foundational stage of AR capability development. It focuses on awareness-building and basic AR/VR competence. At this stage, AR is positioned as an exploratory technology, with emphasis on familiarization rather than curricular integration.
**Stakeholder roles.** Engagement involved a broad stakeholder spectrum, including students, academic staff, industry partners, and members of the wider community. Participation was primarily experiential and observational.
**Accessibility practices.** Accessibility considerations were implicit and addressed mainly through diversified delivery formats, enabling participation across different learner needs and contexts.
**Institutional embedding.** AR activities were institutionally framed as demonstrations and introductory learning opportunities rather than sustained programmes.

Key activities included an open AR/VR demonstration in the BlickBox, organized by the lab, providing a month-long opportunity to experience AR/VR. This event attracted 127 unique visitors, including 67 students and representatives from partner companies, facilitating early academic–industry exchange [52, 53]. Another activity was the provision of complementary hybrid introductory courses within digitalisation modules for international business students. These courses supported foundational AR/VR literacy and awareness of business applications [54]. The other activity was online, self-directed learning implemented in Moodle, which further extended access to foundational content.

### 4.2 All-rounder Phase: Applied Exploration and Networked Learning

**Capability characteristics.** The All-Rounder phase marks a transition from awareness to applied engagement. It is characterized by hands-on development, exploratory design, and contextual learning in real-world environments.
**Stakeholder roles.** Students assumed active roles as designers and developers, while industry partners and external institutions contributed contextual expertise. Academic staff facilitated applied and interdisciplinary learning activities.

**Accessibility practices.** Accessibility considerations remained secondary but began to surface through collaborative design activities and exposure to diverse industrial and institutional contexts.
**Institutional embedding.** Institutional capability expanded through cross-campus and cross-institutional networking, supporting early diffusion of AR practices across the DHBW ecosystem.

Representative activities included student co-design projects, such as an accessible AR escape room addressing gender learning, and AR programming projects using Unity and C# for mobile and HoloLens platforms. This practical approach reinforced technical skills and collaborative competencies [55]. Industrial visits to Dock33, Zeiss, and Voith provided situated insights into AR/VR applications in prototyping, training, and operational optimization [56, 57]. Additional visits to the DHBW Campus Horb and research institutions such as the IWM Mixed Reality Lab reinforced reciprocal learning and interdisciplinary exchange [58].

### 4.3 Specialist Phase: Inclusive Design and Domain-Specific Integration

**Capability characteristics.** This phase reflects a qualitative shift toward domain-specific, research-informed, and accessibility-driven AR implementation. AR capabilities become aligned with specific user groups, pedagogical goals, and disciplinary contexts.
**Stakeholder roles.** Stakeholders transitioned into co-design partners, including non-technical educators, vocational trainers, learners with disabilities, and international collaborators. Research activity became a central driver of development.
**Accessibility practices.** Accessibility was explicitly foregrounded through inclusive and user-centered design, multimodal interaction, and support for blind and low-vision (BLV) and deaf and hard-of-hearing (DHH) users.
**Institutional embedding.** AR practices were embedded within research projects, curricular pilots, and international collaborations, indicating sustained institutional commitment.

This phase is exemplified by improving the accessibility of MirageXR, an open-source AR authoring tool, to support non-technical educators and users with disabilities [4]. Subsequent workshops in agroecology, vocational life skills training, and gamified escape room scenarios demonstrated MirageXR's applicability across "Science, Technology, Engineering, and Mathematics " (STEM) and vocational contexts [13, 59]. Parallel initiatives included AR-based healthcare simulations using HoloPatient [60], accessible AR chemistry laboratories [57], and indoor AR navigation systems for visually impaired users, developed in collaboration with Nelson Mandela African Institution of Science and Technology (NM-AIST) and tested across institutional contexts [61]. Emerging partnerships with community stakeholders further reinforced context-aware AR development [59].

### 4.4 Expert Phase: Consolidation, Scaling, and Knowledge Transfer

**Capability characteristics.** The Expert phase is characterised by consolidation, scalability, and knowledge transfer. AR capabilities extend beyond development toward systematization, dissemination, and sustained institutional use.
**Stakeholder roles.** Faculty communities, institutional leadership, and external networks play central roles in capacity-building, dissemination, and strategic alignment.
**Accessibility practices.** Accessibility is integrated as a normative design consideration, informing both pedagogical and societal AR applications.
**Institutional embedding.** AR is embedded through research dissemination, faculty development activities, hybrid support structures, and forward-looking application planning.

Activities included disseminating research outcomes at institutional and international forums, which support peer exchange and interdisciplinary dialogue [62-65]. Ongoing development of gamified AR applications for vocational education further illustrates the institutionalization of experiential and skills-based learning approaches [66, 67]. Planned hybrid and online AR applications targeting professional training, urban planning, and independent living contexts demonstrate continued strategic expansion [67, 68].

## 5 Discussion

### 5.1 Institutional Capability Development and AR Maturity

The four-phase AR experience journey at DHBW can be interpreted as a trajectory of institutional capability development, rather than a linear progression of technological sophistication. Across the Starter, All-Rounder, Specialist, and Expert phases, maturity emerges through increasing coordination capacity, pedagogical alignment, accessibility integration, and sustainability, rather than through the mere accumulation of AR tools or applications.

In the early phases, AR maturity is characterized primarily by exploratory engagement and proof-of-concept activities. The Starter phase demonstrates how initial exposure and hands-on experimentation foster user engagement and awareness, consistent with prior studies highlighting the motivational affordances of immersive technologies [3]. However, technological integration and institutional coordination remain limited at this stage, reflecting the experimental nature of early adoption. The All-Rounder phase extends this foundation by strengthening cross-sectoral collaboration and applied learning, aligning educational activities with industrial practices and contextualized use cases [21, 63, 64]. While this phase advances organizational learning and stakeholder engagement, accessibility remains peripheral and largely dependent on existing industry solutions.

A qualitative shift occurs in the Specialist phase, where AR maturity becomes increasingly defined by accessibility-aware, pedagogically grounded, and research-informed practices. The co-design of accessible AR authoring tools and inclusive learning scenarios signals a transition from adoption to institutional adaptation, echoing organizational learning perspectives that emphasize iterative refinement and internal capability building. In the Expert phase, maturity is reflected in the consolidation and scaling of AR practices through dissemination, faculty support structures, and systems-level planning. This phase demonstrates sustainability beyond individual projects. Taken together, the findings suggest that accessibility evolves from a marginal consideration into a core indicator of institutional AR maturity, becoming normative rather than optional in later phases.

### 5.2 Accessibility as a Driver of Pedagogical and Institutional Integration

A central analytical contribution of this study lies in demonstrating that AR accessibility functions as a driver of institutional integration rather than an auxiliary design concern. In the Starter and All-Rounder phases, accessibility is primarily addressed at the format level through face-to-face, hybrid, and online delivery modes that broaden participation [69, 70]. While these measures support inclusivity at a basic level, they do not fundamentally reshape pedagogical practices or technological infrastructures [71].

In contrast, the Specialist and Expert phases reveal a shift toward systemic AR accessibility, encompassing tools, workflows, competencies, and institutional support structures. The development of accessible MirageXR and its deployment in co-design workshops with educators, vocational learners, and users with disabilities exemplifies how inclusive design compels closer alignment between pedagogy, technology, and organizational processes [4, 6]. Accessibility considerations influenced not only interface design and multimodal interaction but also authoring workflows, collaboration models, and sustainability strategies, thereby embedding AR more deeply into institutional practice.

This transition underscores the role of inclusive design as a mechanism for scalability. By reducing technical barriers for educators who are not tech experts and meeting the needs of different learners, accessible AR tools can be reused, adapted, and shared across vocational, academic, and community settings. Collaborations with Kolpingwerk, NM-AIST and partners in healthcare and agroecology show that accessibility also helps AR move beyond specific disciplines, making it useful in a wide range of social and institutional settings. In this way, accessibility does more than improve usability; it changes what makes AR practical and valuable in education and institutions.

### 5.3 Implications, Transferability, and Limitations

The results of this study have several takeaways for higher education institutions that want to use AR in ways that are both inclusive and sustainable. Although the tools, partnerships, and scale at DHBW are specific to its context, some parts of the approach can be used elsewhere. These include building capabilities in phases, focusing on important aspects of AR maturity like coordination, teaching methods, accessibility, and sustainability, and using a process-based, qualitative way to track how institutions learn and grow over time.

However, this study does not aim to make broad statistical claims. Instead, it offers insights from a detailed case that can help shape theory and practice in other settings. The specific implementation of tools such as MirageXR, the availability of research infrastructure, and the regulatory and organizational environment of DHBW limit direct replication. Institutions operating under different resource constraints or governance structures may experience alternative trajectories or require adapted maturity pathways.

Several limitations should be acknowledged. The analysis relies primarily on qualitative evidence, including stakeholder feedback, observations, and reflective documentation, rather than longitudinal quantitative measures of learning outcomes or institutional impact. Moreover, while the study captures a multi-year development process, it does not yet provide long-term evidence of sustained effects on graduate competencies or career trajectories. Future research could address these limitations through comparative multi-institutional studies, mixed-method evaluations, and longitudinal tracking of AR-enhanced learning outcomes.

### 5.4 Theoretical and Literature-Based Interpretation

The institutional AR capability trajectory observed in this study can be situated within established theoretical and empirical work on technology adoption, learning theory, and inclusive educational design. Interpreted through the lens of Diffusion of Innovation Theory [19], the progression across the four phases reflects a shift from early experimentation by innovators toward broader institutional uptake. In the initial phases, motivated individuals explore the AR adoption. Later, the organization learned, adapted to its needs, and gradually institutionalized AR practices.

From a pedagogical perspective, the transition toward co-design and AR authoring activities in later phases fits with constructivist learning theory, which values learning through participation and social interaction [72, 73]. By enabling educators and learners to create and adapt AR learning scenarios, the initiative shifted from passive technology use to more active, participatory learning. Including accessibility in these activities also matches the Universal Design for Learning (UDL) approach, making inclusivity a core part of the design instead of an afterthought [74].

Compared with existing AR literature, which often prioritizes technological affordances or isolated classroom interventions [3, 75], this case contributes a process-oriented perspective on AR adoption. The results highlight the need for step-by-step skill building, working with different stakeholders, and designing with accessibility in mind to make AR a lasting part of the institution [6]. Here, accessibility is not just an ethical issue but also helps align teaching goals and makes it easier to scale AR across different settings.

## 6 Conclusion

This case study has documented the accessible AR learning experience journey across DHBW, providing a robust framework for strategic and progressive technology adoption within a higher education institution. The success came from focusing on a humancentered approach that systematically moved AR from a novel concept to an institutionalized educational tool. This was achieved through a phased progression across Starter, All-rounder, Specialist, and Expert phases, which successfully addressed common challenges related to user awareness, digital competency, and, critically, accessibility.

The phased approach demonstrated incremental advancements across seven key success criteria. Initial efforts in the Starter phase focused on building awareness and foundational skills, while the All-rounder phase expanded on this by fostering collaboration with industrial stakeholders and applying AR to real-world contexts. A critical turning point was the Specialist phase, which prioritized inclusive design and co-creation of accessible AR content with and for diverse user groups, aligning the project with core pedagogical theories such as Constructivism and Universal Design for Learning. These efforts culminated in the Expert phase, where findings were disseminated, institutional capacity was built, and a sustainable model for AR integration was established.

This study's contribution to the body of knowledge on AR implementation is an empirical and reflective model of AR maturity in an applied institutional context. The DHBW case offers a crucial blueprint for other organizations, illustrating how a strategic, contextually grounded, and inclusive approach to AR adoption can foster digital innovation. While the study's qualitative focus and institutional specificity present limitations, it provides a powerful testament to this model's effectiveness. Future research should build on these findings with longitudinal and quantitative studies to further validate the long-term impact and scalability of the DHBW framework.

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## References

1. Alhebaishi, S. and R. Stone, *Augmented Reality in Education: Revolutionizing Teaching and Learning Practices – State-of-the-Art.* International Journal of Advanced Computer Science and Applications (ijacsa), 2024. **15**(11).
2. Sharma, A., et al., *Augmented reality – an important aspect of Industry 4.0.* Industrial Robot: the international journal of robotics research and application, 2021. **49**(3): p. 428-441.
3. Akçayır, M. and G. Akçayır, *Advantages and challenges associated with augmented reality for education: A systematic review of the literature.* Educational Research Review, 2017. **20**: p. 1-11.
4. Shidende, D., T. Kessel, and S. Moebs. *Towards Accessible Augmented Reality Learning Authoring Tool: A Case of MirageXR*. in *IST-Africa Conference (IST-Africa)*. 2023. Tshwane, South Africa: IEEE.
5. Shidende, D., et al., *A Systematic Literature Review of Accessibility Evaluation Methods for Augmented Reality Applications.* Studies in Health Technology and Informatics, 2023. **306**: p. 575-582.
6. Quintero, J., et al., *Augmented Reality in Educational Inclusion. A Systematic Review on the Last Decade.* Frontiers in Psychology, 2019. **10**.

7. Li, G., et al., *Augmented Reality in Higher Education: A Systematic Review and Meta-Analysis of the Literature from 2000 to 2023.* Education Sciences, 2025. **15**(6): p. 678.
8. De Lima, C.B., S. Walton, and T. Owen, *A critical outlook at augmented reality and its adoption in education.* Computers and Education Open, 2022. **3**: p. 100103.
9. Rusli, M.S. and Z. Ibrahim, *Augmented Reality (AR) for Deaf and Hard of Hearing (DHH) for animation / Mohamad Saifuddin Rusli and Zainuddin Ibrahim.* e-Academia Journal, 2022. **11**(2): p. 175-186.
10. Du, S., M. Sanmugam, and N.M.M. Barkhaya, *The Impact of Augmented Reality Storybooks on Children's Reading Comprehension and Motivation.* International Journal of Interactive Mobile Technologies (iJIM), 2024. **18**(24): p. 100-114.
11. Şimşek, E.E., *The effect of augmented reality storybooks on the story comprehension and retelling of preschool children.* Frontiers in Psychology, 2024. **15**.
12. Shidende, D. *Design and implementation of accessible open-source augmented reality learning authoring tool*. in *Doctoral Consortium at the European Conference on Technology Enhanced Learning*. 2021. Bolzano, Italy: CEUR-WS. org.
13. Shidende, D., T. Kessel, and A.C. Treydte, *Fostering agroecological knowledge through augmented reality-driven experiential learning.* Form@ re-Open Journal per la formazione in rete, 2025. **25**(1): p. 288-299.
14. Romano, M., D. Paloma, and I. and Aedo, *Empowering teachers to create augmented reality experiences: the effects on the educational experience.* Interactive Learning Environments, 2023. **31**(3): p. 1546-1563.
15. Dengel, A., et al., *A Review on Augmented Reality Authoring Toolkits for Education.* 2022.
16. Kluge, M.G., et al., *Comparing approaches for selection, development, and deployment of extended reality (XR) teaching applications: A case study at The University of Newcastle Australia.* Education and Information Technologies, 2023. **28**(4): p. 4531-4562.
17. Rutten, N. and K. Brouwer-Truijen, *Defining XR-Specific Teacher Competencies: Extending the DigCompEdu Framework for Immersive Education.* Trends in Higher Education, 2025. **4**(1): p. 11.
18. Mystakidis, S., M. Fragkaki, and G. Filippousis, *Ready teacher one: Virtual and augmented reality online professional development for K-12 school teachers.* Computers, 2021. **10**(10): p. 134.
19. Rogers, E.M., A. Singhal, and M.M. Quinlan, *Diffusion of innovations*, in *An integrated approach to communication theory and research*. 2014, Routledge. p. 432-448.
20. Ofosu-Amaah, F.N., *Diffusion of Virtual and Augmented Reality in Pre-K to 12 Education: Experiences and Perceptions of Pioneer Teachers*. 2021, Seton Hall University: New Jersey.
21. Schuir, J. and F. Teuteberg, *Understanding augmented reality adoption trade-offs in production environments from the perspective of future employees: A choice-based conjoint study.* Information Systems and e-Business Management, 2021. **19**(3): p. 1039-1085.
22. Wei, C.Y., et al., *Augmented Reality (AR) as an Enhancement Teaching Tool: Are Educators Ready for It?* Contemporary Educational Technology, 2021. **13**(3): p. ep303.
23. Hammerschmid, S., et al. *A Conceptual Mixed Realities (AR/VR) Capability Maturity Model – With Special Emphasis on Implementation*. in *EuroSPI 2017*. 2017. Cham: Springer International Publishing.

24. Ramanamurthy, S.V., T.K. Jain, and A. Jain, *CMMI for educational institutions.* International Conference on Software Engineering and Mobile Application Modelling and Development (ICSEMA 2012), 2012: p. 8/1-8/5.
25. Guth, L., et al. *An augmented reality-supported facility model in vocational training*. 2021.
26. Buchau, A., et al., *Augmented reality in teaching of electrodynamics.* COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, 2009. **28**(4): p. 948-963.
27. Lauer, L., et al., *Augmented Reality-Toolkit for Real-Time Visualization of Electrical Circuit Schematics.* Fostering Scientific Citizenship in an uncertain world–ESERA 2021 e-Proceedings (angenommen), 2022.
28. Hönig, J., et al., *Mixed-Reality-in-the-Loop Simulation für Schulungen im Maschinen- und Anlagenbau*, in *DELFI 2021 Workshops: Digitalisierung der Bildung*. 2021, Gesellschaft für Informatik: Bonn.
29. Florian, L., *Virtuelle Welten der Geometrie: Planung, Durchführung und Auswertung einer praxisorientierten Lehrveranstaltung für angehende Mathematiklehrkräfte*, in *DELFI 2021 Workshops: Digitalisierung der Bildung*. 2021, Gesellschaft für Informatik: Bonn.
30. Ratter, M., J. Klöckner, and M. Kaufeld, *Augmented Reality in der Ausbildung an Hubschrauberkonsolen. Ein empirischer Lernmittelvergleich zu Nutzungserlebnis und Lernerfolg*, in *DELFI 2021 Workshops: Digitalisierung der Bildung*. 2021, Gesellschaft für Informatik: Bonn.
31. Tene, T., et al. *Integrating immersive technologies with STEM education: a systematic review*. in *Frontiers in Education*. 2024. Frontiers Media SA.
32. Stylianidou, N., et al., *"Helping Nemo!"—Using augmented reality and alternate reality games in the context of universal design for learning.* Education Sciences, 2020. **10**(4): p. 95.
33. de Moraes Rossetto, A.G., et al., *An analysis of the use of augmented reality and virtual reality as educational resources.* Computer Applications in Engineering Education, 2023. **31**(6): p. 1761-1775.
34. Gaol, F.L. and E. Prasolova-Førland, *Special section editorial: The frontiers of augmented and mixed reality in all levels of education.* Education and Information Technologies, 2022. **27**(1): p. 611-623.
35. Fernandez, M., *Augmented virtual reality: How to improve education systems.* Higher Learning Research Communications, 2017. **7**(1): p. 1-15.
36. Badilla-Quintana, M.G., E. Sepulveda-Valenzuela, and M. Salazar Arias, *Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs.* Sustainability, 2020. **12**(19): p. 8116.
37. Henne, A., et al., *How to Evaluate Augmented Reality Embedded in Lesson Planning in Teacher Education.* Education Sciences, 2024. **14**(3): p. 264.
38. Gómez-Galán, J., et al., *Socio-educational impact of Augmented Reality (AR) in sustainable learning ecologies: A semantic modeling approach.* Sustainability, 2020. **12**(21): p. 9116.
39. Yin, R.K., *Case Study Research and Applications: Design and Methods*. 6th ed. Vol. 6. 2018, CA: Sage Publications, Inc
40. Creswell, J.W. and C.N. Poth, *Qualitative inquiry and research design: Choosing among five approaches*. 2016: Sage Publications.
41. Denzin, N.K., *Triangulation 2.0.* Journal of mixed methods research, 2012. **6**(2): p. 80-88.

42. Patton, M.Q., *Qualitative research & evaluation methods: Integrating theory and practice*. 2014: Sage Publications.
43. Campbell, S., et al., *Purposive sampling: complex or simple? Research case examples.* Journal of research in Nursing, 2020. **25**(8): p. 652-661.
44. Denny, E. and A. Weckesser, *How to do qualitative research? Qualitative Research Methods.* Bjog, 2022. **129**(7): p. 1166.
45. Palinkas, L.A., et al., *Purposeful sampling for qualitative data collection and analysis in mixed method implementation research.* Administration and policy in mental health and mental health services research, 2015. **42**(5): p. 533-544.
46. Braun, V. and V. Clarke, *Using thematic analysis in psychology.* Qualitative Research in Psychology, 2006. **3**(2): p. 77-101.
47. Moser, A. and I. Korstjens, *Series: Practical guidance to qualitative research. Part 3: Sampling, data collection and analysis.* European Journal of General Practice, 2018. **24**(1): p. 9-18.
48. Huang, Q., *Comparing teacher's roles of F2f learning and online learning in a blended English course.* Computer Assisted Language Learning, 2019. **32**(3): p. 190-209.
49. Martin, F., T. Sun, and C.D. Westine, *A systematic review of research on online teaching and learning from 2009 to 2018.* Computers & Education, 2020. **159**: p. 104009.
50. Means, B. and J. Neisler, *Teaching and Learning in the Time of COVID: The Student Perspective.* Online Learning, 2021. **25**(1).
51. Raes, A., *Exploring Student and Teacher Experiences in Hybrid Learning Environments: Does Presence Matter?* Postdigital Science and Education, 2022. **4**(1): p. 138-159.
52. Gavish, N., et al., *Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks.* Interactive Learning Environments, 2015. **23**(6): p. 778-798.
53. Huang, W., et al., *Computer-Supported Collaboration: Theory and Practice*. 2024: John Wiley & Sons. 388.
54. Ibokessien, N., *Exploring the use of Virtual and Augmented Reality technologies in Business Studies Education.* UK Academy for Information Systems Conference Proceedings 2021, 2021.
55. Buchner, J. and M. Kerres, *Students as Designers of Augmented Reality: Impact on Learning and Motivation in Computer Science.* Multimodal Technologies and Interaction, 2021. **5**(8): p. 41.
56. Bower, M., M.J.W. Lee, and B. Dalgarno, *Collaborative learning across physical and virtual worlds: Factors supporting and constraining learners in a blended reality environment.* British Journal of Educational Technology, 2017. **48**(2): p. 407-430.
57. Samson, F., D. Shidende, and S. Moebs. *Accessible Augmented Reality Chemistry Lab for Students in Developing Countries*. in *2024 IST-Africa Conference (IST-Africa)*. 2024. Dublin, Ireland: IEEE.
58. IWM. *Future Innovation Space: The future at your fingertips*. Available from: https://www.iwm-tuebingen.de/en/experience/futureinnovationspace.
59. Law, E.L.-C., *Augmented reality educational applications: let's find out what students and teachers need!* Actas del Congreso Internacional de Ingeniería de Sistemas, 2021: p. 49-63.
60. DHBW Stuttgart. *EdCon - News*. 2024 2024; Available from: https://www.dhbw-stuttgart.de/forschung-transfer/wirtschaft/projekte/abgeschlossene-projekte/edcon/news/.

61. Samson, F., et al. *Accessibility Features for Augmented Reality Indoor Navigation Systems*. in *AFRICATEK 2023*. 2024. Cham: Springer Nature Switzerland.
62. Huang, H., G.-J. Hwang, and S.-C. Chang, *Facilitating decision making in authentic contexts: an SVVR-based experiential flipped learning approach for professional training.* Interactive Learning Environments, 2023. **31**(8): p. 5219-5235.
63. Kwon, H.-J., et al., *Design of Augmented Reality Training Content for Railway Vehicle Maintenance Focusing on the Axle-Mounted Disc Brake System.* Applied Sciences, 2021. **11**(19): p. 9090.
64. Cheng, K.-H. and C.-C. Tsai, *Affordances of augmented reality in science learning: Suggestions for future research.* Journal of Science Education Technology, 2013. **22**(4): p. 449-462.
65. Samson, F., D. Shidende, and S. Moebs. *Harnessing XR Technologies for Education and Training*. in *Online Educa Berlin*. 2024. Berlin.
66. Song, T., et al. *ElderEase AR: Enhancing Elderly Daily Living with the Multimodal Large Language Model and Augmented Reality*. 2025. New York, NY, USA: Association for Computing Machinery.
67. Kayyali, M., *Aligning Vocational Education With Industry Needs: Successful Partnerships and Practices*, in *Innovative Approaches in Vocational and Regional Education*. 2025, IGI Global Scientific Publishing. p. 1-48.
68. Mardis, M.A., et al., *Assessing alignment between information technology educational opportunities, professional requirements, and industry demands.* Education and Information Technologies, 2018. **23**(4): p. 1547-1584.
69. Seale, J., *E-learning and Disability in Higher Education: Accessibility Research and Practice*. 2 ed. 2013, New York: Routledge. 280.
70. Kelly, L.P.B., *Holistic approaches to e-learning accessibility.* Research in Learning Technology, 2006. **14**(1): p. 69-78.
71. Cooper, M., *Making online learning accessible to disabled students: an institutional case study*, in *Approaches to Developing Accessible Learning Experiences*. 2013, Routledge. p. 103-115.
72. Vygotsky, L.S. and M. Cole, *Mind in Society: Development of Higher Psychological Processes*. 1978: Harvard University Press. 180.
73. Chand, S.P., *Constructivism in education: Exploring the contributions of Piaget, Vygotsky, and Bruner.* Children, 1995. **10**.
74. Almeqdad, Q.I., et al., *The effectiveness of universal design for learning: A systematic review of the literature and meta-analysis.* Cogent Education, 2023. **10**(1): p. 2218191.
75. Garzón, J. and J. Acevedo, *Meta-analysis of the impact of Augmented Reality on students' learning gains.* Educational Research Review, 2019. **27**: p. 244-260.