Research Article

Developing Effective Augmented Reality Learning Applications: Integrating Key Pedagogical Principles

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Abstract

Augmented reality is becoming increasingly popular in education owing to visualisation, real time interaction and dynamic content. There has been extensive research to design effective learning experiences with the help of Augmented Reality, but research indicates that lack of pedagogical design based on pedagogical principles can lead to pedagogical issues in Augmented Reality based Learning Environments thereby limiting their effectiveness in achieving learning objectives. The pedagogical elements and technological tools must be integrated as per framework based on pedagogical principles to design effective Augmented Reality based learning applications to create meaningful learning experiences. This research paper aims to synthesise collect, categorise, and prioritise the pedagogical principles specific for the design and development of augmented reality learning environments. with the help of educators and technical experts. The analytical and synthetic approach to reviewing the pedagogical principles involved an iterative process. A total of 53 articles were analysed and 21 pedagogical principles were selected and categorised into five categories 1) Pedagogy and Instructional Design 2) Technology Integration 3) Assessment and Feedback 4) Collaboration and Community 5) Holistic and Inclusive approach. These principles will be valuable for Augmented Reality designers, researchers and educators for developing pedagogically effective Augmented Reality based learning environments.

Key words: Educational Technology, Augmented Reality, Pedagogical Principles, K-12 Education, Mobile learning.

Introduction

Augmented Reality (AR) is emerging as an educational technology that augments digital information with real life information to make the teaching learning process more engaging and effective (Bower et al., 2014). This digital content can take many forms like two-dimensional or three-dimensional images, videos, animations, text, audio olfactory of tactile stimulus that can enhance user's perception of reality. Analogous to virtual reality experience user experiences interactivity with digital components in AR based learning environments (Nincarean et al., 2013a). However, user remains enacted in real world making it more suitable for classroom situations for use by children of all ages. The review of research literature review indicates that AR learning environments can help achieving learning objectives in effective manner by having a positive impact on learner motivation, engagement and

understanding of concepts (Khan et al., 2019).

Milogram and Kishno in 1994 referred to the term mixed reality for representation of AR and Virtual Reality (see Figure 1).

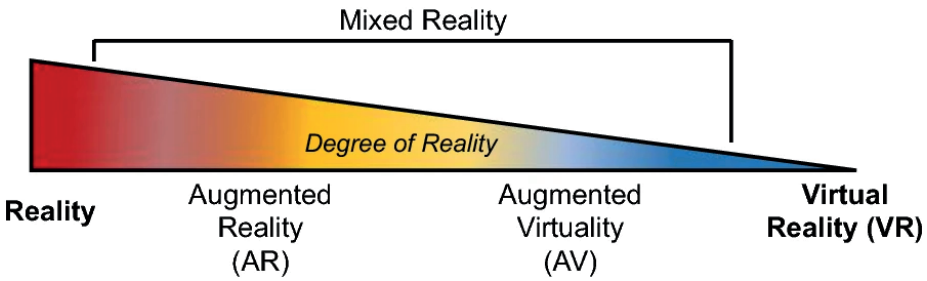

Fig. 1: VR Continuum [Miligram and Kishno 1994]

In vision-based Augmented Reality, real life objects or images can be used as triggers for augmentation. Some examples of vision-based Augmented Reality are AR pop up books that uses QR codes within textbooks to view video with the help of digital devices AR glasses or PDA's (smartphones or tablets) that has camera functionalities (Kidd and Crompton, 2016). These are easy to implement and thus substituting other alternatives in current AR market. User can point his device camera towards the trigger object and Augmented Reality software will provide augmentation related to this object. In location-based AR systems digital devices make use of Global Positioning System (GPS) to display augmented reality content by accessing the physical location of the real-life object (Brigham, 2017).

Although use of Augmented Reality is becoming increasingly popular in all sectors including education, however the strong potential of AR as an educational technology to provide effective learning experiences requires addressing of barriers that exist in seamless integration of AR technology in classrooms. Due to rapid technological advancements in education, the students and teachers of current generation have access to mobile devices and Internet (Wang et al., 2018a).

Existing research on use of AR in education provide evidence regarding the positive impact of AR technology on learner motivation, learning outcomes and memory retention of students (Khan et al., 2019).

Augmented Reality supports multiple representation of data and visualization that helps in easy understanding of abstract concepts. This technology engages learners with the help or real time interaction with 3-D learning content. It facilitates collaborative learning opportunities and reduces cognitive load thereby improving learning gains (Nashirah Nor Mahadzir & Funn Phung, n.d.). Augmented Reality-based simulations foster learning by discovery-based learning where learner can explore and experiment, building 21st century skills, cognitive thinking and promoting higher order skills. It has positive impact on learners' willingness to learn by involving learners in learning process. As augmented reality technology is continuously evolving, applications designed for education have undergone lot of changes since its introduction in 1995 from their technological and pedagogical point of view. The challenges and issues faced by users of this technology also keep on changing with time (Wu et al., 2013a).

Challenges and issues in Augmented Reality Learning Environments

Some challenges and issues that are encountered in use of AR technology in classrooms include usability issues, technical problems (availability of infrastructure, internet access etc.), digital skills of teachers and students and pedagogical issues in AR applications. It has been observed that when new educational technology is introduced there is more focus on implementation of technology than pedagogies or learning objectives of implementation. But research indicates that technology and [Grazon 2019 pedagogy are two key components of sustainable learning environment (Garzón, 2021a; *Radu 2014*, n.d.)

Designing pedagogically effective Augmented Reality Learning Environments

It is important to consider that effectiveness of AR applications not only depends on technical characteristics or features of application but also on pedagogical accuracy of these AR applications with respect to the educational context. The learning application may be effective in one context but not in another context relevant to learning needs of the learners(Lai and Cheong, 2022b). Pedagogical issues highlighted by various studies focus on not considering the pedagogical aspects of applications in design of AR based Learning environments limiting their effectiveness as an educational intervention(Akçayır and Akçayır, 2017a; Wu et al., 2013a).

Researchers and practitioners acknowledge that AR can be used to design effective immersive and engaging learning environments but it is not necessary that all AR based learning environments are effective rather AR based learning environments can be ineffective as well if not designed as per pedagogical considerations(Garzón & Acevedo, 2019). Research investigating the effectiveness of AR tools based on empirical evidence can help in analyzing the factors responsible for design of AR learning environments that result in effective learning(Tzima et al., 2019a). (Bizami et al., 2023; Tzima et al., 2019b)[Bucher 2023]. None of the previous studies have used pedagogical approach as research variable or presented any findings regrading pedagogical strategies to implement AR in educational settings (Garzón, 2021a) [Garzon and Acevedo 2019].

Research indicates that to make this integration pedagogically effective there is need to connect pedagogy and technology in meaningful ways based on relevant learning theories in immersive and innovative learning environments. There is a need for Techno pedagogy mapping (Bizami et al., 2023) to link pedagogical and technological elements in a learning application.

Pedagogical principles for design of augmented reality based learning environments

Pedagogical principles play an important role in effective pedagogical and technological design of educational technologies(Parmaxi and Demetriou, 2020). These principles guide the development of educational technologies and focus on appropriate teaching strategies, instructional design and methods assessment for meaningful learning experiences(Bidarra and Rusman, 2017). The pedagogy for integration of educational technologies like AR is continuously evolving but as per Blooms Taxonomy pedagogical theory it should invoke higher order thinking in learners and create authentic learner experiences(Fowler, 2015; Pedagogical Principles for Development of Effective Augmented Reality Learning Applications, n.d.; Turvey and Pachler, 2020).

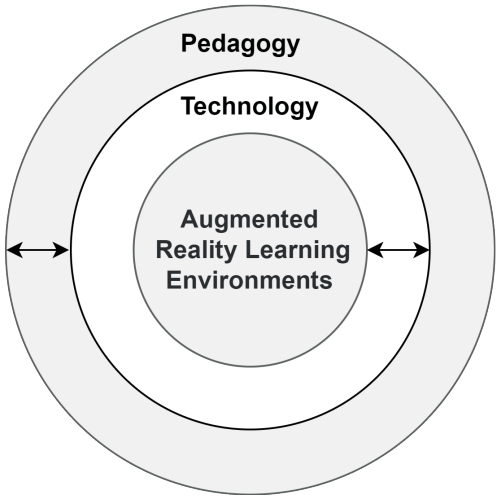

Fig. 2: Two-way relationship between technology and pedagogy in Augmented Reality Learning Environments

In current scenario, teachers lack technical and pedagogical knowledge required for implementation of AR [Kohler Mishra 2005], traditional methods of instruction and delivery of content are teacher centric and not learner centric, and integration of technology is not based on Technological Pedagogical Content Knowledge (TPACK) framework. This turns students into passive learners who are unable to apply their knowledge in real contexts in order to solve problems. There is a need for reflection upon learning to encourage memory retention of the knowledge acquired. Learners are not passive there is need to consider learner agency and characteristics. This will facilitate opportunities to create learning experiences where teacher co-constructs knowledge with students from prior experience and apply this knowledge in real life situations to create authentic learning experiences. AR can act as promising solution to enhance learning process and increase effectiveness when implemented as per pedagogical theories like constructivism (da Silva et al., 2019).

Need and Significance of Study

It is very important to bridge technological and pedagogical affordances by design and development of Augmented Reality Learning Environments based on pedagogical principles specific for use of AR technology in education(Akçayır & Akçayır, 2017b). This will encourage using suitable pedagogical approaches and strategies, age-appropriate content and learning activities, considering learner characteristics and style for design of pedagogically efficient AR applications(Atjonen et al., 2011a).

Research Questions

1. What are pedagogical challenges and issues in existing AR Learning Environments?
2. What are the important pedagogical principles that guide development of effective Augmented Reality based Learning Environments?

Research Methodology

The methodology of this study is divided into three separately performed

phases to ensure a structured and analytical approach for identification of pedagogical principles (see Figure 3). We used five step process for identifying pedagogical principles for design of AR applications.

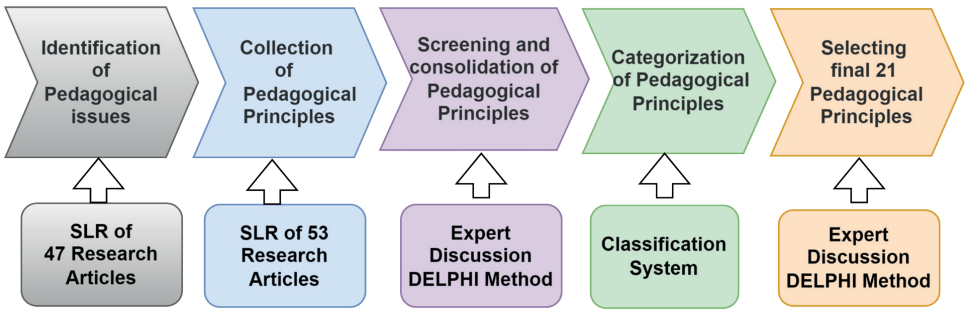

Fig. 3: Research Methodology

Systematic Literature review and Teacher survey for identifying pedagogical issues. The pedagogical issues in AR applications were identified from existing literature of 59 studies using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses(PRISMA) approach and confirmed by the survey involving 276 teachers(Figure 4).

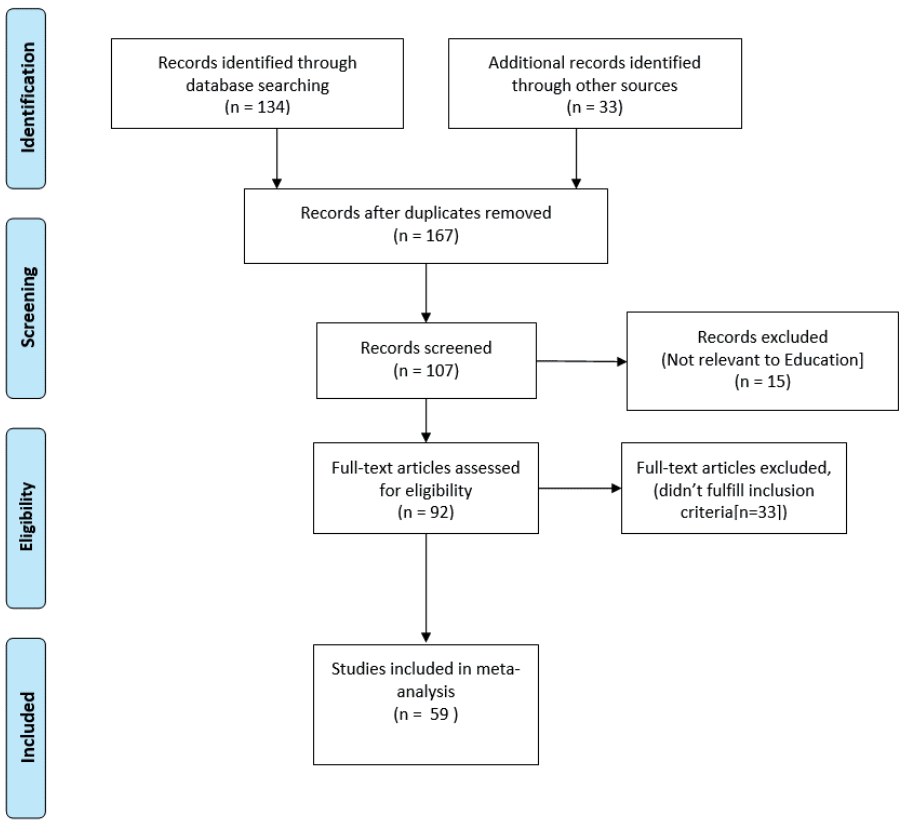

Fig. 4: Prisma Flow Diagram

The study followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework in Systematic Literature Review for identifying pedagogical principles for augmented reality learning environments. The PRISMA framework (Jobin et al., 2019) was used for searching five databases based using specific keywords, screening and review (based on inclusion and exclusion criteria) including research articles from 2000-2023.The search yielded 138 research articles and finally only 47 articles (as per Figure 5) were used for further analysis to answer research questions of this study.121 relevant pedagogical principles were identified and extracted after analysis of 47 research articles focusing on pedagogical principles for the use of AR applications in educational settings.

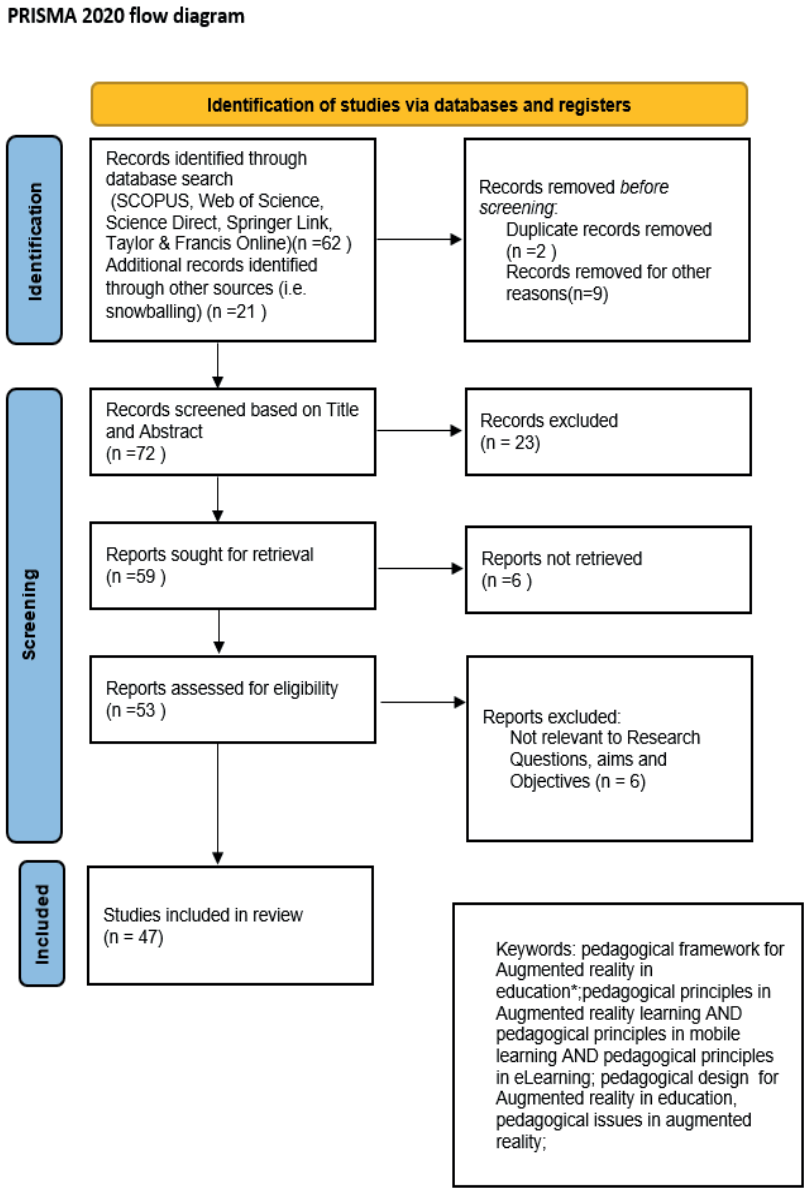

Fig. 5: Prisma Flow Diagram

Delphi method was used for the selection of pedagogical principles and the method consisted of five repeated iterations of discussions led by the same expert's panel. The pedagogical principles collected during the first phase were consolidated by a team of 20 Delphi experts.

Then, these experts reviewed the consolidated pedagogical principles and shortlisted 45 pedagogical principles by eliminating irrelevant principles and combining the similar ones to avoid redundancy.

After the screening of principles 21 pedagogical principles were selected by the Teachers and Delphi expert's panel.

The final 21 pedagogical principles were grouped into five thematic categories by the experts based on the classification system.

Results and Discussion

Pedagogical issues in AR Learning Environments

The most common pedagogical issues reported in the existing AR applications include lack of effective instructional design, meaningful integration between pedagogical and technological elements (Wang et al., 2018b). Another issue is alignment between learning objectives, curricular goals, content or tasks that not developmentally age appropriate, less opportunities for collaborative learning. These applications don't support authentic learning by solving problems relevant to real life context. These learning environments doesn't cater individual learning needs and styles of learners by customisation of content and tasks, lack co-learning opportunities for teachers and parents(Akçayır and Akçayır, 2017b; Radu, 2014). Moreover, the learning theories like constructivism that promotes learning by experiences and considers learner agency as an important factor for active learning. Technology integration is not is not based on frameworks like TPACK and Substitution, Augmentation, Modification, and Redefinition (SAMR) framework to balance three essential elements i.e. content pedagogy and technology for effective teaching and learning process (Hamilton et al., 2016a; Koehler and Mishra, 2009). Other important pedagogical issues identified from literature include novelty factor affecting learning gains, cognitive overload in students, teacher resistance towards AR adoption etc(Hsu, 2017; Radu, 2014). There is need to address these issues for effective integration of AR technology into educational settings that can result in enhancing learning gains and provide meaningful teaching and learning experiences (Keengwe and Bhargava, 2014). This can be done by designing the AR learning environments based on specific pedagogical principles that will align pedagogical theories with this technology.

Pedagogical issues in AR Learning Environments

Several pedagogical issues have been identified in Augmented Reality (AR) applications developed for education from existing literature. One significant issue is that these AR applications doesn't provide customized content and tasks to address diverse learning needs by considering learning styles, agency, existing knowledge of learner and learning contexts(Keengwe and Bhargava, 2014; Radu, 2014;

Wu et al., 2013b) .The AR learning environments lack collaborative learning opportunities(Eh Phon et al., 2014) that are vital for involving teachers and parents as co-learners and scaffolded learning. There is less focus on critical thinking and building of 21st century skills in learners in response to modern educational demands such as Industry 4.0 principles. Due to which sometimes learning with AR results in cognitive overload(Bizami et al., 2023; Garzón, 2021b), feeling of isolation and distractions(Sırakaya and Alsancak Sırakaya, 2022). ARLE doesn't have significant effect on achieving learning objectives for which it has been designed. This may be due lack of coherence between technological, pedagogical elements and content that fails to retain focus on short term and long-term academic goals of the application (Anna Helena). The absence of specific pedagogical principles based on learning theories suitable for AR, as well as pedagogical design frameworks hampers its effective integration into curriculum (Garzón, 2021b; Lai and Cheong, 2022a; Parmaxi and Demetriou, 2020) .Teachers' resistance to (Lai and Cheong, 2022a; Parmaxi and Demetriou, 2020)integrate AR technology into their classrooms (Hamilton et al., 2016b; Nincarean et al., 2013b) due to demand for additional class time and large classroom size(Hsu, 2017) make it challenging to implement(Kazanidis and Pellas, n.d.; Sırakaya and Alsancak Sırakaya, 2022). Teachers often face challenges in customization of AR applications to tailor their needs and preparation of teaching materials for AR as they lack technical capabilities(Buchner and Kerres, 2023; Parmaxi and Demetriou, 2020). The limited interactivity in design of AR technologies can lead to learner usability issues(Albayrak and Yilmaz, 2022) (Tuli and Mantri, 2020), attention tunneling(Tzima et al., 2019b) and novelty factor(Kazanidis and Pellas, n.d.; Sırakaya and Alsancak Sırakaya, 2022). However, the AR can positive impact on learning gains and learning motivation but lack of instructional design for AR based instruction makes it difficult for teachers and learners to create authentic learning experiences (Akçayır and Akçayır, 2017b; Kazanidis and Pellas, n.d.).These challenges suggest a need robust pedagogical design based on pedagogical standards and principles that can foster enhanced and effective learning experiences in AR Learning environments(Garzón et al., 2019; Garzón and Acevedo, 2019).

Pedagogical Principles for design of effective Augmented Reality Learning Environments

After analysing the existing literature and collecting 112 pedagogical principles, a meeting was conducted with 20 experts having more than five years' experience in teaching and use of AR technology to eliminate redundancy and consolidate similar principles. We selected 45 principles by deleting the duplicate entries and combining the related ones. 21 principles were finalised after conducting another meeting with an expert panel using the Delphi process(Figure 6). The principles were validated with the help of 220 teachers from 43 schools with more than 03 years of experience in teaching with the aid of educational technologies.

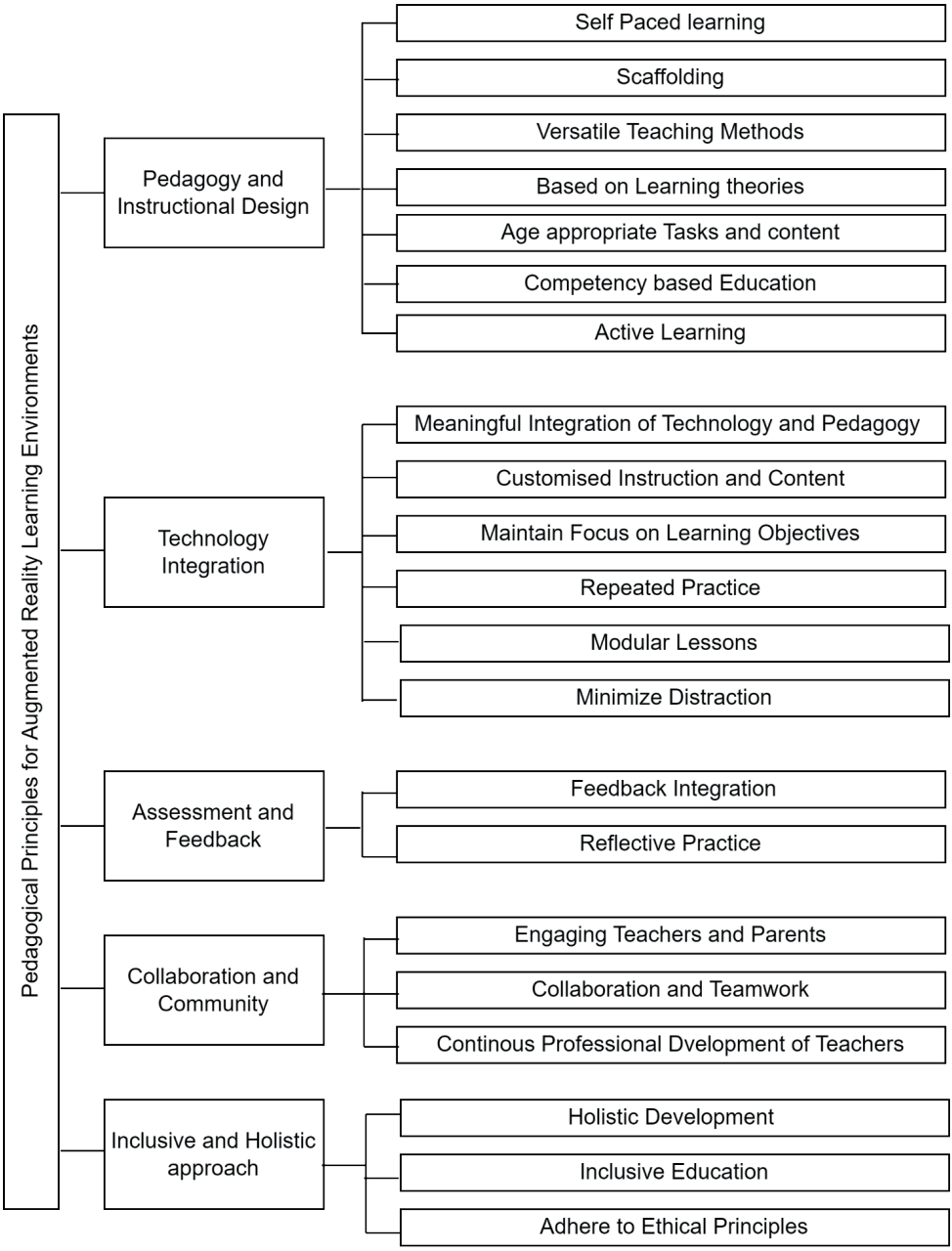

Fig. 6: Pedagogical principles for Augmented Reality Learning Environments

The pedagogical principles were grouped into five categories using classification system. The relationship between each pedagogical principle was identified using an inter-relationship matrix. The results of the exploratory factor analysis test applied to the 21 pedagogical principles were used for categorisation. The principles having factor loading of at least 0.6 were retained while as the ones with factor loading less than 0.6 were rejected (see Table 1).

Table 1. Results Obtained from Principal Component Analysis with Varimax Rotation.

Principles	Components				
	Factor 1 (Pedagogy and Instructional Design)	Factor 2 (Technology Integration)	Factor 3 (Assessment and Feedback)	Factor 4 (Collaboration and Community)	Factor 5 (Inclusive and Holistic Approach)
Self-paced	0.65	0.12	0.05	-0.03	0.02
Scaffolding	0.68	0.09	-0.04	0.05	0.01
Employs versatile teaching methods	0.61	0.06	-0.02	0.08	0.04
Based on learning theories	0.68	0.15	-0.01	0.02	0.05
Age-appropriate tasks	0.60	-0.02	0.03	0.09	0.04
Competency-based education	0.64	0.08	0.02	0.06	0.07
Active learning	0.63	0.10	-0.01	0.04	0.03
Modular lessons	0.66	0.07	0.02	0.05	0.06
Meaningful integration of technology and pedagogy	0.08	0.61	0.05	0.04	-0.01
Customized instruction and content	0.09	0.65	0.04	0.02	-0.02
Maintain focus on Learning Objectives	0.04	0.63	0.08	-0.03	0.05
Minimize distraction	0.03	0.62	0.06	0.02	0.04
Repeated practice	0.05	0.69	0.07	0.01	-0.01
Feedback integration	-0.02	0.03	0.60	0.02	0.06
Reflective practice	0.05	0.02	0.63	0.04	0.01
Engaging parents and teachers	0.06	0.04	0.01	0.68	0.08
Collaboration	0.08	0.03	0.05	0.69	0.07
Continuous teacher professional development	0.07	0.06	0.02	0.61	0.09
Holistic development	0.03	-0.01	0.05	0.07	0.64
Inclusive education	0.02	0.05	0.02	0.06	0.62
Adhere to ethical principles	0.04	0.07	0.01	0.05	0.69

The pedagogical principles were categorised into 5 different groups: Pedagogy and Instructional Design, Technology Integration, Assessment and Feedback, Collaboration and Community, Inclusive and Holistic approach (Figure 7).

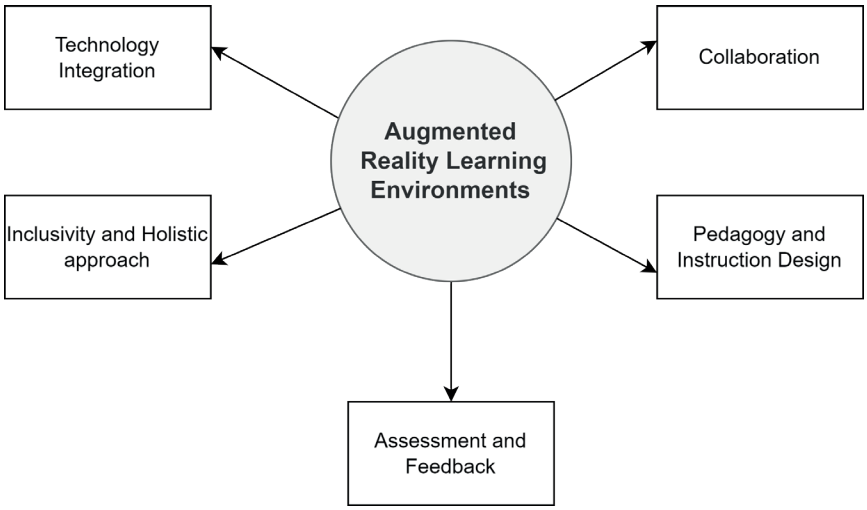

Fig. 7: Categories of Pedagogical Principles for Augmented Reality Learning Environments

Pedagogy and Instructional Design: This category of principles focuses on the pedagogical design, use of suitable teaching methods and strategies and instructional design for effective use of AR technology. It emphasizes on creating engaging and effective learning experiences customized as per learner styles and pedagogical needs.

Principle 1: Self-paced Learning-Augmented Reality Learning Environments should provide flexibility of space, speed, style and time to the learners. The learner should be able to control and adjust the sequence of activities in learning environment as per their personal preferences learning interests and needs. This flexibility in AR applications can lead to high levels of learner engagement and improved learning outcomes(Bacca et al., 2019; Park, 2011; Pelz, n.d.-a).

Principle 2: Scaffolding-This can help in reducing cognitive overload in learners by providing support for building skills or acquiring knowledge. In Augmented Reality Learning Environments this can be done by guided tutorials help and hints in activities until learner attains proficiency to handle the tasks in an independent manner(Atjonen et al., 2011b; James & Pollard, n.d.). This can help with learner motivation of children by enhancing peer interaction.

Principle 3: Employs Versatile Teaching Methods-Learner centric methods and strategies should be employed so that multiple senses of learners are engaged in the learning process. Learning should be provided in formal as well informal contexts. This will result in active learner participation and provide personalized learning experiences(Anderson & Mccormick, 2005a).

Principle 4: Based on Learning Theories-Augmented Reality Learning Environments design should be based on learning theories like constructivism that encourages learners to build their knowledge based on interactions with the environment. Augmented Reality Learning Environments should support realistic interactions and experiences with the help of 3-D

visualisations between the learner and the environment to stimulate them and engaging actively in learning process(Ozdamli, 2012).

Principle 5: Developmentally Age-appropriate Tasks-It is crucial that all the tasks and digital content in must be age appropriate and suitable as per the cognitive abilities of learners. Younger students need simple interfaces as they can't handle complex tasks. Use of complex design or content can confuse students and cause frustration in them while as older learners can interact with complex and open-ended tasks(Koenraad, 2019; Park, 2011).

Principle 6: Competency-based Education -Augmented reality environments can support learners in acquiring real life skills or competencies owing to its interactive learning experiences that can mimic real life contexts. Learners can gain hands on experience with the help of immersive hands-on sessions for various activities and practice various skills easily and effectively (Ozdamli, 2012; Pelz, n.d.-b).

Principle 7: Active Learning-Learner must play an active role in the learning process ask questions, analyses and think in a rational manner, construct knowledge by exploring. Inquiry based learning and critical thinking can help in cognitive development and higher order skills of students (Ozdamli, 2012; Park, 2011; Tarnavska and Glushanytsia, 2019).

Technology Integration: This category focuses on principles for integrating technology in educational settings so that pedagogy technology and content aligns to attain short term learning objectives and long-term curricular goals.

Principle 8: Meaningful Integration of Technology and Pedagogy-To design effective learning environments that there is need for creating meaningful interactions of technology, pedagogy and content where AR is not mere a passive tool for delivering information rather it will provide enhanced and interactive learning experiences to understand abstract concepts and complex phenomena with the help of visualisation(Keengwe and Bhargava, 2014; Okojie et al., n.d.; Taopan, 2020).

Principle 9: Customised Instruction and Content-As every learner is different and has unique learning style, the use of AR technology can adapt to learner needs at Realtime, the environment must take learner agency, prior knowledge and background of learner into consideration and create individual pathways of learning. This creates relevant and meaningful learning experiences (Burden et al., 2019; Park, 2011).

Principle 10: Maintain focus on Learning Objectives-The Augmented Reality Learning Environments must ensure that the pedagogy, content and assessment to be coherent with each other in order to retain focus on achievement of learning objectives for each learning activity. This will result in the accomplishment of long-term curricular goals for which Augmented Reality Learning Environments has been designed (Anderson and Mccormick, 2005a; Atjonen et al., 2011b).

Principle 11: Repeated Practice-in Augmented Reality Learning Environments can provide opportunities for drill and practice of tasks for mastering of skills or gaining better understanding of concepts and retention of information in long term memory of learners (Gargrish et al., 2021; Ozdamli, 2012).

Principle 12: Modular Lessons-The use of discrete modules can help in self-directed learning and when information is divided into chunks it is easy for as human mind to understand and retain

it. Each module should be integrated with formative assessment for providing differentiated instruction on the basis of real-time feedback (Burden et al., 2019; Park, 2011) (Anderson and Mccormick, 2005a; James and Pollard, n.d.).

Principle 13: Minimise Distraction-Careful Design of AR applications that have simple interface and is easy to use, must take care that there are no external distractions that divert attention of learners during learning activities. It is important to minimize distractions so that learner remains focused on learning content(Anderson and Mccormick, 2005b; Tuli and Mantri, 2020).

Assessment and Feedback: This category focuses on principles feedback that provide guidelines on assessment and feedback for evaluation of student learning progress and to support using assessment data for customising instructional practices, learning activities and content.

Principle 14: Feedback Integration-Continuous and immediate feedback is crucial to assess the learning progress during the learning process. The adaptive feedback mechanism in Augmented Reality Learning Environments can help in customizing the content and learning strategies as per the performance of the learner(Bikanga Ada, 2018). The assessment will be based on techniques like rubrics, peer basement and self-assessment(Anderson and Mccormick, 2005a; James and Pollard, n.d.).

Principle 15: Reflective Practice-This will encourage learners to review their learning process and identify areas where they need improvement. With the help of Augmented Reality Learning Environment(ARLE) they can adjust their learning strategies, repeat the learning tasks to reinforce their understanding and accomplish learning outcomes effectively(Tarnavska and Glushanytsia, 2019; Torres et al., 2016).

Collaboration and Community: This category of principles focuses on creating a collaborative learning environment involving students, parents, and teachers in co-creating knowledge. These principles highlight use of teamwork and professional development of teachers to enhance effectiveness of AR based educational environments.

Principle 16: Engaging Parents and Teachers as part of the Learning Community- Involving teachers and parents for co-construction of knowledge can build a learning community. This will provide support and reinforcement(Burden et al., 2019) (Pelz, n.d.-b)

Principle 17: Collaboration and Teamwork-Collaboration and teamwork will allow learners to work together on finding solutions to the problem(Torres et al., 2016), sharing of ideas, fostering communication, facilitate interaction with peers and connect with co-learners from different learning spaces(Lai and Cheong, 2022b; *Moocs Principles*, n.d.; Simuth & Sarmany-Schuller, 2012).

Principle 18: Continuous Teacher Professional Development-There is need for capacity building of teachers for effective use of AR technology in teaching learning process. The PD program of teachers should focus on equipping them with knowledge and skills of pedagogical strategies to integrate AR technology in the curriculum(Law et al., 2007; Ozdamli, 2012).

Holistic and Inclusive approach: This category focuses on principles for responsible use of technology by adhering to ethical principles, catering to learning needs of diverse learners in order to provide equitable learning opportunities. These principles emphasize on the overall growth of students across all domains of development.

Principle 19: Holistic Education-Integration of Augmented Reality should include activities that enhances development of learners capabilities across all the seven key domains of development, that is, cognitive and critical thinking, emotional intelligence, physical motor skills and health, social skills, moral and ethical values, creative and spiritual growth (Lai and Cheong, 2022a).

Principle 20: Inclusive Education-AR LE must accommodate the learning needs and preferences of all learners irrespective of abilities, gender and backgrounds. AR design should focus on intuitive interfaces and incorporate activities as well as content that ensures equitable and inclusive learning opportunities for all learners(Anderson and Mccormick, 2005a; Wang et al., 2018b).

Principle 21: Adhering to Ethical Principles-Augmented Reality Learning Environments design must adhere to ethical principles like accessibility and privacy of data, inclusive design and content, responsible use of technology and appropriate content(Koenraad, 2019; Siragusa et al., 2007).

Table 2: Pedagogical Principles

Category	Principle	Description
Pedagogy and Instructional Design	Self-paced	Provide learners with flexibility to learn at their own pace and style. Encourage learners to engage in learning at their own speed and style.
	Scaffolding	Makes use of scaffolded learning to reduce cognitive overload
	Employs versatile teaching methods	Use versatile student centric teaching practices to nurture critical thinking and engage students
	Based on learning theories	Learning process should be based on learning theories like constructivism.
	Age-appropriate tasks	All the learning tasks and content must be developmentally appropriate for learners
	Competency-based education	Focus on building 21st-century skills like communication, critical thinking and creativity
	Active learning	Involve learners in the learning process and encourage use of experiential activities.
	Modular lessons	Incorporate chunking of information and use a modular approach
Technology Integration	Meaningful integration of technology and pedagogy	Technology integration based as per TPACK, SAMR model, and UDL frameworks
	Customized instruction and content	Customize content after considering the learner's characteristics.
	Maintain focus on Learning Objectives	The pedagogy, content and technology must be aligned and coherent for achievement of learning objectives and curricular goals
	Minimize distraction	Minimize the elements that cause distraction in learners
	Repeated practice	Integrate the redundancy principle of retrieval and repeated practice for memory retention

Category	Principle	Description
Assessment and Feedback	Feedback integration	Uses formative and summative assessment based on techniques like rubrics, peer assessment and self-assessment
	Reflective practice	Prompts learners to think and reflect upon their learning and connect knowledge with real life contexts
Collaboration and Community	Engaging parents and teachers	Involve parents and teachers as co-learners with the students
	Collaboration	Support opportunities for collaboration, sharing of ideas and teamwork
	Continuous teacher professional development	Comes with teacher training modules and tutorials for teachers for use of AR technology.
Inclusive and Holistic approach	Holistic development	Ensure growth across all domains of development i.e. cognitive, physical, aesthetic, ethics etc.
	Inclusive education	Supports inclusive education by providing learning opportunities for diverse group of learners
	Adhere to ethical principles	Must adhere to ethical principles like maintaining privacy, accessibility, and responsible use of technology

These pedagogical principles will focus on pedagogical aspects of AR technology[See Table 2]. The set of principles will be useful for designers for learning activities and content, guide teachers for designing teaching learning techniques, use of age-appropriate tasks and activities, suitable instructional method and practices for planning, learning and continuous formative assessment to address diverse learning needs of students and facilitate integration of AR technology into existing curriculum. There is need to involve teachers into pedagogical design and evaluation process of Augmented Reality Learning Environments. As per the recommendations of Fernandez, six step methodology should be used to help AR adoption of AR instructional design model: i) training of teachers ii) developing conceptual frameworks iii) involving teachers and programmers in development and designing of educational architecture within Augmented Reality Learning Environments (Mystakidis et al., 2022). Based on existing Chang and Wang Bista man frameworks, STF (Studio Thinking framework) by Hetland in 2007(Okojie et al., n.d.).There is need for considering SAMR model i.e. SAMR (substitution augmentation modification and redefinition) model to select suitable educational technology and evaluate its effectiveness(Bistaman et al., 2018) reflect on issues institutions and teachers face in incorporating AR into pedagogy for both formal and informal learning environments. Pedagogical content knowledge perspective of teacher reviews or decides the appropriate AR based content to be included or excluded, based on learner needs and characteristics like age, target group etc. and choice of didactical approach to be used.it also refers how AR is implemented in Learning Environments and how it works for achieving learning outcomes (Taopan,

2020). the design of Augmented Reality Learning Environments must support authentic learning, connect knowledge to real world problems and experiential learning. Another important aspect to be considered for design of Augmented Reality Learning Environments is relevance of information provided or level of enrichment in knowledge(Buchner and Kerres, 2023).

The Augmented Reality Learning Environments must follow holistic evaluation model i.e. a rubric designed as formative assessment tool suitable for multidimensional evaluation across different domains(Mystakidis et al., 2022; Ozdamli, 2012). In teacher centric environment, teacher must be confident in making use of AR for lesson planning and delivery. Teachers must have sufficient knowledge and skills that allow them to select appropriate instructional strategy or approach(Law et al., 2007). Learning technology by design adopt technology to design specific learning environments that correspond with specific learning objectives or instructional methods and curricular goals (Koehler and Mishra, 2009).

Conclusion

Effective pedagogical design is crucial for development of AR Learning applications that meet the learning needs of the target group, promotes use of teaching methods that encourage learning experiences. The pedagogical design of AR tools should be guided by pedagogical principles that provides a robust framework for integration of AR technology, aligns educational content, technological affordances and pedagogical elements with the educational goals of the application. These principles ensure professional development and support for educators to ensure effective implementation of technology in educational settings. Pedagogical principles for AR in education emphasise the integration of cognitive activities, use of suitable teaching methods based on learning theories, and adaptability to modern challenges. These principles are essential for fostering creativity and critical thinking in learners by focusing on components of learning that are crucial for developing their creative abilities. Design and development of learning environments should maintain focus on educational value and cognitive relevance of content and activities to ensure that AR as an educational technology enhances the learning motivation and student engagement by creating individual learning experiences that considers learner agency and can be customised based on formative assessment and feedback from learners. Integrating AR technology into educational settings requires adherence to these pedagogical principles to achieve learning outcomes. These 21 principles address different dimensions broadly grouped within five main sections that provide guidelines for instructional analysis, design, delivery and evaluation phases of AR learning environments in order to optimise their pedagogical quality and focus on creating engaging, inclusive, and effective learning environments.

Incorporating these pedagogical principles in the design of AR applications will benefit students by contributing towards the holistic development of children across physical, cognitive and social domains. It will also result in increased acceptance of AR as an educational technology in the classrooms by teachers and students. The proliferation of mobile based AR applications is increasing as these applications can be used easily with the help of mobile phones and doesn't need internet for operation making it cost effective and accessible

for everyone. This can help in bridging the digital divide in students belonging to different geographical locations and disadvantaged sections of society.

As the young generation being digital natives rely mostly on technology for learning process, AR applications provide joyful and engaging learning experiences to children helping in long term retention of concepts and increased motivation to learn.

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