Vladimir Geroimenko *Editor*

Augmented Reality Games II

The Gamification of Education, Medicine and Art

Second Edition

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ISBN 978-3-031-54474-3 ISBN 978-3-031-54475-0 (eBook)
https://doi.org/10.1007/978-3-031-54475-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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This book is dedicated to future generations of augmented reality game players and designers.

With sincere gratitude to the British University in Egypt and especially to the Faculty of Informatics and Computer Science.

Preface

The first edition of this book was published in 2019 as Volume II of the first ever two-volume research monograph about augmented reality games. In Volume I, the phenomenon of the Pokémon GO game was analyzed in theoretical, cultural, and conceptual contexts, with emphasis on its nature and the educational use of the game.

The current, second edition of the book continues to explore the exciting field of augmented reality games and their enabling technologies. The new edition has been thoroughly revised and updated, with 6 new chapters included. As well as investigating augmented reality games in education, the book provides a comprehensive analysis of augmented reality games in medicine, healthcare, and art. It explores the latest ideas in game developments and introduces novel and challenging topics to facilitate a conceptual and critical understanding of augmented reality games as a new type of serious and fun games.

The book deals with a wide range of topics: educational augmented reality games, the gamification of elementary and secondary education, teachers' novel key skills and new teaching methods in the classroom, creating immersive and playful reading experiences, augmented reality games for health promotion in old age and for transforming dental and physical education and practice, the gamification of augmented reality art, pervasive games, gaming in public spaces, and many others. It has been written by a team of 43 researchers, practitioners, and artists, pioneering in developing and researching the new type of computer games. The book's contributors are from 12 countries all around the world (Australia, Brazil, Egypt, Germany, Hungary, the Netherlands, Romania, Serbia, Slovenia, Spain, Switzerland, and the USA).

Intended as a starting point for exploring the new fascinating area of research and game development, the book will be essential reading not only for researchers, practitioners, game developers, and artists, but also for students (graduates and undergraduates) and all those interested in the rapidly developing area of augmented reality games.

This book can be considered as part of a series of nine pioneering monographs published by Springer on the same subject of augmented reality and with the same editor, namely:

1. *Augmented Reality Games II: The Gamification of Education, Medicine and Art.* Geroimenko V (Ed.), 2nd Edition, Springer, 2024
2. *Augmented Reality and Artificial Intelligence: The Fusion of Advanced Technologies*. Geroimenko V (Ed), Springer, 2023
3. *Augmented Reality Art: From an Emerging Technology to a Novel Creative Medium.* Geroimenko V (Ed), 3rd Edition, Revised and Updated, Springer, 2022
4. *Augmented Reality in Tourism, Museums and Heritage: A New Technology to Inform and Entertain.* Geroimenko V (Ed), Springer, 2021
5. *Augmented Reality in Education: A New Technology for Teaching and Learning.* Geroimenko V (Ed), Springer, 2020
6. *Augmented Reality Games I: Understanding the Phenomenon of Pokémon GO*. Geroimenko V (Ed), Springer, 2019
7. *Augmented Reality Games II: The Gamification of Education, Medicine and Art.* Geroimenko V (Ed.), Springer, 2019
8. *Augmented Reality Art: From an Emerging Technology to a Novel Creative Medium.* Geroimenko V (Ed), 2nd Edition, Springer, 2018
9. *Augmented Reality Art: From an Emerging Technology to a Novel Creative Medium.* Geroimenko V (Ed), Springer, 2014

The book's 17 chapters, which can be read in sequence or randomly, are arranged in 3 parts as follows:

Part I "Augmented Reality Games in Education" includes 7 chapters (Chaps. 1–7):

Chapter 1 "Educational Augmented Reality Games" states that augmented reality (AR) games within the education sector hold the potential to revolutionize the learning experiences by introducing innovative forms of education. However, it remains unclear how these AR games, characterized by diverse game genres, can effectively integrate into traditional educational processes, considering various theoretical learning paradigms and models. The chapter addresses this gap in knowledge by conducting a comprehensive analysis of game genres, learning paradigms, and theories applied in diverse AR games within the educational domain. The authors present various AR games developed in the academia as well as commercially available AR games in the field of education, which they classified by year of publication, school subject, game genres, AR systems, learning environment, learning paradigms and theories, target groups, research method, and study sample size (the last two just for the games in academia). The classified data was analyzed to identify how AR games, rooted in various game genres, contribute to the enhancement of the educational process. The findings of this analysis shed light on the intersection between AR game design, theoretical paradigms, and learning models, offering insights into the potential benefits for education and guidelines for designing AR educational games across different contexts.

Chapter 2 "New Horizons for Digital Youth: Augmented Reality and the Gamification of Elementary and Secondary Education" (a new chapter in this edition) discusses the use of augmented reality in a variety of educational settings in elementary and secondary school. In an age where captivating students' interest and attention has become more difficult, in part due to widespread smartphone usage, teachers must

devise new ways to engage their classrooms. Importantly, AR is a technology that often requires smartphone use, thus capitalizing on the technology already held at student fingertips. The chapter discusses the relationship between AR games and enriched experiences for child and adolescent users. Focusing on elementary and secondary school curricula, this chapter highlights potential positive and energizing youth experiences using the gamification of science, mathematics, history, English, arts, music, and general socialization. The chapter concludes with the discussion of the responsibilities and roles of parents, educators, and students in maintaining the safety of AR for youth.

Chapter 3 "A New Key Competence: Teachers' Methodological Knowledge of Augmented Reality and Its Gaming Potential" (a new chapter in this edition) examines the transformative integration of augmented reality and gaming in contemporary education. Rooted in digital pedagogy, it explores the theoretical framework of digital pedagogy, highlighting the role of gamification in enhancing learning engagement. Augmented reality is examined as a powerful tool for creating immersive learning experiences, with real-world examples provided. The changing roles of teachers in the digital era are outlined, emphasizing the need for a shift toward student-centered approaches. Additionally, the chapter addresses the key competencies required in the networked learning space, focusing on the teacher's role in developing digital literacy and information processing skills in learners. The concluding sections advocate for crafting evidence-informed pedagogical strategies aligned with AR and gaming, emphasizing the importance of being open to change, consistently reflecting on the progress in student learning and the need for continuous professional development for educators.

Chapter 4 "Augmented Imagination: Creating Immersive and Playful Reading Experiences" considers reading as a complex process that is changing dramatically during the ongoing evolution from purely physical books to digital ones. Between the two poles of physical and digital, there is an emerging field where physical is being augmented by digital and vice versa. In this chapter, the authors investigate physical and digital approaches to the phenomenon of book augmentation. Physical approaches do not embed any electronic elements into the book. On the contrary, in digital approaches interactivity is supported by embedding electronic devices into the physical book, holding devices above the book or by placing electronic devices around the reader. Firstly, the authors describe and analyze 10 augmented books that use different augmentation techniques (along the following three dimensions: the modalities being used, the type of content on offer, and the impact of the augmentation on the reading flow). They then emphasize the need for further investigation of the ways for delivering multimodal and immersive content, in which the processes of reading the original text, interacting, and consuming the digital content merge into one unified experience that does not disrupt the reading flow and enhances the sense of immersion in the story. Finally, we illustrate how we could move toward this vision of a unified augmented reading experience using different technologies, such as: speech recognition systems, eye- and head-tracking systems, generative AI, olfactory displays, smell synthesizers, and digitally controlled food delivery systems.

Chapter 5 "Learning to Build a Doric Temple: The Augmentation of Knowledge Through AR Gamification" (a new chapter in this edition) proposes a digital learning instrument for ancient architecture and history, taking as the object of learning a Doric temple from the ancient city of Callatis, an early Greek colony on the Black Sea. An augmentation of the in-situ reality and knowledge through AR and gamification is proposed in the form of a mobile application named DORIC, representing a puzzle game. The puzzle's goal is the completion of a 3D reconstruction of a Doric temple. This is achieved by scanning the archeological fragments of an ancient Doric temple and by visualizing in AR the different stages of this reconstruction augmented with documentary videos. Several gamification elements are provided within the game with the purpose of stimulating the users' interest and motivation and rewarding their partial and final effort to complete the puzzle. The chapter elaborates on the research context related to AR, serious games and gamification in education and archeology, and further details on how the DORIC application was creatively designed to maximize the visual and, hence, the educational outcomes, and, finally, discusses and summarizes these outcomes, highlighting the authors' contribution and novelty.

Chapter 6 "Explorations in Mixed Reality with Learning and Teaching Frameworks: Lessons from Ludus and the Vulcan Academy" explores the design of mixed reality frameworks for learning and teaching at Griffith University, Gold Coast, Australia. Discipline areas from Pharmacy and Design have developed a series of experiential learning scenarios that help build rich frameworks in which to learn, teach, and assess, using and testing multiple strategies in the process. Essential to teaching methods is the implementation of learning objectives as moderated by strategies of play-based learning. The learning scenarios range from developing mobile applications to impact upon spatial reasoning beyond the device frame, designing transformative experiences through student led content authoring of augmented game content, to immersion in a virtual pharmacy with access to augmented content through head mounted displays. Increased engagement is a key objective of the gamified learning experience, and our experiments seek to investigate the boundaries between educational theories as applied to mixed reality environments through active learning and inquiry-based instruction. The findings demonstrate that play, through the use of mixed reality technologies, can benefit and prolong student engagement, but importantly that the student can have ownership of the experience. The technological frameworks are not just seen to have novelty but are effective tools for deeper and lasting levels of engagement.

Chapter 7 "Novel Teaching Methods in the Classroom: The Use of Augmented Reality Games" introduces the increase of augmented reality games as one of the current technologies used by teachers around the world. Games and apps can be a very important tool and support to expand the perception of students in the classroom or to bring the outside world in. Whether students are watching videos of current events or manipulating interactive models in the apps, AR can add an extra layer of depth to lessons, allowing a direct interaction and enabling a differentiated sensory immersion. As students can play, watch, and create, they may benefit from the empathy in the process, if a large potential for creative ways to build social and emotional skills through content learning. As results observed in the recent literature involving the use

of AR games and apps in an educational perspective, it is possible to conclude that AR technology in education can effectively make students learning and understanding complex concepts in a more engaging and interactive way. Other relevant aspects that can be considered are present in the contribution to an increase in the level of fun and the potential for collaboration among students in the classroom, as well as to learn effectively and meaningfully. Augmented reality provides an exciting and fascinating learning environment as it increases the motivation and attractiveness of teaching and learning in real-life scenarios for students.

Part II "Augmented Reality Games in Medicine and Healthcare" comprises 5 chapters (Chaps. 8–12):

Chapter 8 "The Unexplored Potential of Playful Ambient Projection-Based AR to Improve Well-Being" explores how projection-based AR can be used in built environments to improve well-being of occupants. Stress, discomfort, or sedentary behavior are factors that have a negative impact on people's well-being and efficiency. A number of ambient prototypes have been developed to help people address these issues. In parallel, gamification techniques have been successfully used in applications that aim to improve people's health by encouraging them to change their behavior. In this chapter, the authors first describe several ambient and augmented reality prototypes that aim to improve people's well-being. Next, they discuss the idea of ambient projection-based AR providing situated interaction "in motion" in users' environment, coupled with the concepts of playfulness, gamification, peripheral, and calm technologies, in order to incite users' behaviors toward improving well-being. The authors continue by describing a scenario and discussing technical considerations for its implementation. While different concepts encompassing the proposed idea have been explored individually, the whole idea presents an untapped potential that has yet to be explored.

Chapter 9 "Augmented Reality Games for Health Promotion in Old Age" shows how augmented reality game concepts can be used for health-related purposes in old age. Physical activity is a key aspect for healthy aging. Conceptual considerations and current research in the field of technology and aging are examined here to recommend designs for augmented reality games for older adults. The authors explore relevant trends in augmented reality and possibilities to integrate this technology into individual health promotion. Research on the use of mobile devices and applications by older people and older adults' interest in using this technology for health-related purposes is presented. From this, the authors deduce older adults' readiness to use augmented reality games on mobile devices in their everyday lives and for health promotion. Design recommendations include considerations of which technology is used by older people, how to create meaningful games, how to involve older adults' social networks, issues of data security, and the special requirements for designing health-related augmented reality games as a whole. The combination of empirical findings from gerontological and technical research groups allows us to discuss these issues in a broader perspective and define relevant factors for developing augmented reality games for older adults.

Chapter 10 "The Healing App: Augmented Reality and Art for Pediatric Patients with Chronic Pain" states that healthcare is a large and ever-expanding industry affecting millions of people every day. Therefore, it makes sense that the medical community is already discovering the benefits of augmented reality. Training, live surgical guidance, and therapy are already popular areas of AR in medicine. However, what if we also harnessed the freedom of augmented reality to influence pain management with art? In collaboration with artist Claudia Hart, the Montefiore Health System is creating a new project that explores the combined power of art and technology in a healthcare environment. By commissioning Claudia Hart for a specific area of a hospital, in a situation where she is an intimate part of the planning, a magical and meaningful space emerges that could directly affect overall patient experience and even the need for pain medications. The authors believe their work together in art, design, and technology is the future of healthcare and patient environments.

Chapter 11 "From Boring to Engaging: Using Gamification to Transform Dental Education and Practice" (a new chapter in this edition) delves into the application of gamification in dentistry, with a specific focus on its impact on both patients and dental education. It discusses gamification as a distraction tool, particularly in pediatric dentistry, utilizing various devices. Furthermore, it emphasizes the significance of interactive games and simulations in engaging patients. The chapter introduces serious games for dental students and clinicians, underlining their pivotal role in skill development within dental education. Additionally, it delves into the necessary resources for creating serious games, with particular emphasis on the integration of 3D models into applications and serious games. Ethical considerations and limitations are also comprehensively examined, offering a comprehensive view of the potential benefits and challenges associated with gamification and serious games in the field of dentistry.

Chapter 12 (a new chapter in this edition) "The Gamification of Physical Education Using Augmented Reality Technology" addresses the innovative approaches that make physical education more engaging and stimulating for students. Two methods on the rise that excel in achieving this goal are gamification and the use of augmented reality. Gamification has been highlighted as a methodology that can transform the teaching-learning process into something more attractive for students as it applies game elements in the educational context. Augmented reality seeks to enhance and diversify educational activities by providing students with interactive and stimulating experiences by superimposing virtual elements on their physical environment. Devices such as tablets, mobile phones, and augmented reality glasses can use this technology. Likewise, the combination of gamification and augmented reality in physical education allows the creation of an innovative educational environment that motivates students to actively participate in physical activities, develop their motor skills, adopt healthy habits, and understand theoretical concepts. In this chapter, the possibilities of using augmented reality to gamify physical education are explored, with a detailed overview of the benefits and challenges. The chapter also discusses in detail how this technology can be introduced into the classroom and provides examples of previous implementations. Finally, an example of a practical proposal for

physical education using augmented reality technology is presented, accompanied by detailed and sequential instructions for its implementation.

Part III "Augmented Reality Games in Art" consists of 5 chapters (Chaps. 13–17):

Chapter 13 "The Gamification of Augmented Reality Art" discusses augmented reality, gamification, and its relation to media culture and art. Augmented reality exists in many applications, including gaming, education, industry, research, and art. Gamification refers to merging games with interactive media (video games, virtual and augmented realities, for example) to allow for the completion of difficult digital research labor in a more fun, intuitive fashion. In this chapter, the author discusses the merging of gamification and augmented reality-based art and its impact on digital labor, as well as examples of augmented reality that exhibit gamification or elements of it. Speculative design fictions of gamified augmented reality are examined to determine possible future outcomes of this genre. Lastly, historical experiments in user interface design are mentioned to propose future solutions for augmented reality applications, artistic installations, and gamification scenarios.

Chapter 14 "Unintended Consequence: Pervasive Games and Public Art" investigates how Pervasive Games using augmented reality can contribute to a changing perception of Public Art through a playful exploration of place. By unintentionally discovering Art while playing games, new meanings are seen to emerge and are explored from new perspectives through the surprise of discovery and renegotiation with art in public places. This chapter is a semiotic exploration, through analysis and interview of some of the signs and symbols of Public Art and particularly the ontological shifts arising from the re-contextualization and revisitations of symbols in augmented frameworks. The analysis of semiotic change seeks to explore the shifting interpretations of Public Art afforded by playing games with augmented technologies. Pervasive Games such as Wayfinder Live, and even Pokémon GO, and its precursors unravel an evolving set of rich discourses in which to investigate the recursive correlations of Art and Place. The outcomes of this analysis of Pervasive Games reveal the ontological implications not of intentional design, but of the unintended consequence of playing Games through Art.

Chapter 15 "Defacing the 'Balloon Dog': Art, Algorithmic Culture and Augmented Reality" examines gamification through selected artworks that deploy augmented reality techniques. Gamification is approached as a form of "algorithmic culture" in which algorithms can be, to varying degrees, both positively guiding and negatively coercing a user. After analyzing examples of gamification in the mobile entertainment industry, such as Snapchat and Pokémon GO, examples from contemporary media art that blend augmented reality techniques with algorithmic structures and tendencies are investigated. This research considers AR as a processual entity, rather than a discrete form or technical medium. Its interfaces are not simply dynamically engaged across the physical and the digital but entangled with social and cultural forces.

Chapter 16 "Circumpolar Gamifications in the Age of Global Warming: Ice Levels, Anxiety and the Anthropocene" looks at the representations of both culture and nature from the circumpolar north in mixed reality and video games. This is explored through an historical analysis of video games set in the Arctic, focusing

mostly on Alaska, with a few works from media outside of mixed reality and video games discussed. The essay illustrates a history of games set in the Arctic, paired with how polar cultures are or are not accurately represented, what effects the global discussion on climate change has on these representations as well as the role of Indigenous sovereignty and justice. These issues are all compounded by a global anxiety associated with climate change/global warming that leads to eschatological perseverations. The video game Never Alone is the quintessential example of how northern culture and environmental issues can be used in a video game without the follies of vestigial colonialist thinking. AR works from the Dirigibles of Denali project by Nathan Shafer and Patrick Lichty are discussed in these new contexts, with an emphasis on biomes, anthromes, and a new hybrid concept, the infome, which is a digital anthrome. Conclusions drawn are that Indigenous communities in the circumpolar north need to retain the control over their own infomes, which would include knowledge of their biomes and cultures, and how those are represented by the outside.

Chapter 17 "Augmented Reality Gaming in Public Spaces: Dealing with Non-player Characters or Having a Shared Experience?" (a new chapter in this edition) dives into the practice of using of augmented reality in public spaces and the chance that strangers (accidentally) enter your mixed reality scenery. In which situations is that a problem? And what are the solutions or approaches to deal with that properly? The focus is on one approach in particular: finding ways to embed people into an AR scene, instead of trying to avoid that from happening. Referring to two case studies, this chapter provides insight into the aspects that matter when designing or using an AR game with strangers playing a role in the experience as non-playable characters (NPCs).

Lastly, we hope that the reader will not judge the book's editor and contributors too harshly. We have accepted the challenge of being the first, and we have done our best to bring out the 2nd edition of this pioneering work on augmented reality games. Just go ahead and read this research monograph. We hope sincerely that you will enjoy it.

Cairo, Egypt Vladimir Geroimenko

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Part I
Augmented Reality Games in Education

Chapter 1
Educational Augmented Reality Games

Maheshya Weerasinghe, Aaron Quigley, Julie Ducasse, Klen Čopič Pucihar, and Matjaž Kljun

Abstract Augmented reality (AR) games within the education sector hold the potential to revolutionise the learning experiences by introducing innovative forms of education. However, it remains unclear how these AR games, characterised by diverse game genres, can effectively integrate into traditional educational processes, considering various theoretical learning paradigms and models. This chapter addresses this gap in knowledge by conducting a comprehensive analysis of game genres, learning paradigms, and theories applied in diverse AR games within the educational domain. We present various AR games developed in the academia as well as commercially available AR games in the field of education, which we classified by year of publication, school subject, game genres, AR systems, learning environment, learning paradigms and theories, target group(s), research method and study sample size (the last two just for the games in academia). The classified data was analysed to identify how AR games, rooted in various game genres, contribute to the enhancement

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V. Geroimenko (ed.), *Augmented Reality Games II*,
https://doi.org/10.1007/978-3-031-54475-0_1

of the educational process. The findings of this analysis shed light on the intersection between AR game design, theoretical paradigms and learning models, offering insights into the potential benefits for education and guidelines for designing AR educational games across different contexts.

1.1 Introduction

The delivery and acquisition of knowledge and skills in schools or universities are undergoing constant change as the interplay between new forms of pedagogy, new technologies and new styles of education emerge. A prime example of this is when games, game-based learning and gamification are incorporated into the curriculum. Such developments are often motivated by a desire to improve student engagement, student-centred learning and enhanced learning experiences.

Digital games are gaining increased visibility in education providing an enhanced experience in learning. Research and practice have demonstrated that games are effective with respect to learning and retention (Cox 2014; Pak 2011). Gamification has furthered the possibilities in raising engagement and motivation in educational applications with the use of game design elements and game principles in the teaching and learning contexts.

Within this context, interest in connecting physical and digital elements of a learning experience has emerged. Augmented reality (AR) technology has the potential to mix virtual and real objects, allowing users to experience mixed content in various dimensions such as spatial, contextual and temporal. Among others, this creates an opportunity for exploring experiential student-centred learning rather than the typical educator-centred learning where users observe the educator.

However, prior to understanding AR games for learning or more broadly digital games in education, it is important to first understand the theoretical underpinnings of education. A variety of theoretical frameworks and theories of learning can form the basis for understanding how, and where, AR games might be incorporated into an educational context. This theoretical foundation is timely and important as today there are a plethora of research prototypes combining AR, digital games and gamification. These developments have fuelled the exploration of this approach in knowledge delivery and transfer. By understanding these foundations, we can better understand the challenges and issues and reflect on these as we survey the AR games for education already developed.

As a result, this chapter will analyse AR games for education through various variables such as subject focus, game genres, technology used, learning environment, learning paradigms, theories and activities, research methods used and target group(s). We first discuss learning paradigms, theories and models that describe the educational concepts, frameworks and practices used in teaching and learning. Secondly, we explore digital games, their genres and how gamification and games-based strategies might be used to sharpen the learning experience in the field of education. Next, in the method section, we explain how we identified and selected

papers that describe AR games in educational settings and present some examples. In the fifth section, we categorise and analyse selected AR game studies according to the year of publication, school subject, research question or study aim, research method, game genre, AR system, learning environment, target group(s), learning paradigm and learning theories. Finally, based on these analyses, we explore the current status of AR games in education, focusing on future implementations.

1.2 Teaching and Learning Paradigms and Theories

When discussing AR games in education, it is hard to overlook the teaching and learning paradigms and theories. Nevertheless, educational games are always based on these and understanding them can clarify some game design decisions. Learning theories are conceptual frameworks that describe how people acquire, process and retain knowledge during the learning process. They fall into one of several learning paradigms, including behaviourism, cognitivism, constructivism and others. The wealth of scientific work and results in this field has expanded greatly during the twentieth century but is far from being understood in its entirety. In this section, we present a brief overview of the field.

Different theories are appropriate for different situations and learning outcomes. There is no single accepted definition of learning, since it depends on one's point of view or a learning paradigm. Most commonly accepted learning paradigms suggest that learning is

- a visible change in one's behaviour, which can be measured (Ashworth et al. 2004; Boeree 2000) (i.e. providing feedback in a game to learners and providing reinforcement to positively impact performance).
- the active process of acquisition (including insight, information processing, memory, perception) of new knowledge and developing adequate mental constructions (Ashworth et al. 2004; Innovative Learning 2011) (i.e. stimulating various regions of the brain and increasing the number of consolidation processes through repetition, improving reflexes, promoting critical thinking and helping people learn).
- an active, socially enhanced process of knowledge construction based on one's own subjective interpretation of the objective reality (Ashworth et al. 2004; University of Sydney 2011) (i.e. collaboratively and cooperatively engaging in a task in order to achieve a goal in a game).
- a natural desire of human beings, a means of self-actualization and developing personal potentials (Ashworth et al. 2004; Simply Psychology 2015) (i.e. learning in a game through a cycle of concrete experiences, reflective observation, abstract conceptualization and active experimentation).
- the process of connecting to information sources containing actionable knowledge and maintaining those connections (Ashworth et al. 2004; Kop and Hill 2008) (i.e.

leveraging game skills that are transferable across media, platforms and tools to expand students' learning networks).

Theories within the same paradigm share the same basic point of view (Ashworth et al. 2004). It has to be stressed that each of the paradigms has attracted both supporters and critics. Presenting all possible views is beyond the scope of this chapter and what follows is a brief overview of the paradigms mentioned above.

Behaviourism states that all behaviours are learned through the interactions with the external environment. Behaviourists do not attempt to analyse the inner processes of mind such as thoughts, feelings or motivation. From a behaviourist perspective, a learner starts off as a clear state and simply responds to environmental stimuli. These responses can be shaped through positive and negative reinforcement (a reward for desired or a punishment for undesired behaviour), increasing or decreasing the probability of repeating the same behaviour (Ashworth et al. 2004; Boeree 2000). Behaviourist principles are commonly seen in learning tools including quizzes, discussions and questions and answers, as well as sequenced skills-based learning such as AR-enabled language learning. Such tools utilise reinforcement through immediate feedback and gamification. For example, feedback in the AR game EduPARK (Pombo et al. 2017) allows learners to monitor their process and respond accordingly by changing their learning behaviour.

Cognitivism is a learning paradigm focused on the inner mental processes of humans: how the human brain perceives things, how it makes memories and creates new knowledge (Ashworth et al. 2004; Innovative Learning 2011). Cognitive approach to learning sees the learner as an active participant in the learning process, acquiring new knowledge and constructing mental constructions based on prior knowledge and experience. Unlike behaviourism, it tries to understand the complex cognitive processes by searching for associations between learning and information processing, perceptions and memory. AR games can be designed to help stimulate various regions of the brain such as to improve reflexes, promote critical thinking and help people learn different patterns of associations. For example, AR games designed based on cognitivism are helpful when used to learn a foreign language and memorise new material.

Constructivism is a learning paradigm claiming that learners construct their own knowledge of the world through experiencing things and reflecting on those experiences (Ashworth et al. 2004; University of Sydney 2011). Constructivism's approach to learning differs from behaviourism and cognitivism in that it perceives learning as an active, socially supported process of knowledge construction. As such, learners construct their own subjective interpretation and meaning of what is being learnt of objective reality. AR games offer many opportunities for working with physical and conceptual materials to construct new knowledge. AR game-based constructivist activities might include taking photos, recording videos and/or sound, editing and integrating that perceptual information, across multiple sensory modalities, with the user's environment in real time. For example, AR game Leometry (Laine et al. 2016) is a collaborative AR application where students construct 3D mathematical

and geometrical models in a shared AR workspace, allowing new dynamic opportunities for playful interactions to promote higher-level learning, and to help develop personal meanings. It is an example of the use of constructivism.

Humanism defines learning as a natural human desire, based on self-actualization and development of personal potentials (Ashworth et al. 2004; Simply Psychology 2015). It emphasises the importance of every individual in that they are striving towards happiness through self-achievement while being responsible for their own actions. Individuals should also have control over the learning process, which should be based on observing and exploring. The learning process is considered more important than the learning outcomes. Since the control is in the learner's hands the role of the teacher is to encourage, motivate and provide reasons for embarking on the learning journey. AR games can be used to capture and curate experiences of individuals and transform those experiences into knowledge. Such AR games can also be used to gather evidence from an experience and afterwards to communicate, analyse and visualise the knowledge gained based on personal requirements. For example, the AR game Table Mystery (Boletsis and McCallum 2013) that helps to learn the elements of the periodic table, which is created through the transformation of experience, is an example of the use of Humanism.

Connectivism claims that learning occurs not only in individuals but also within and across networks. As such, learning resides also outside an individual such as within an organisation or web. The connections and the network of an individual are thus more important than their current state of knowledge. Connectivism is proposed as a learning paradigm for the digital age, which attempts to approach learning and knowledge in the context of technological development (Ashworth et al. 2004; Kop and Hill 2008). Connectivist learners share and communicate dynamic knowledge creation through networked interaction with machines and other people. The collaborative AR games, which are coupled with the resources available through connectivity, make connectivism an important paradigm for knowledge gathering. AR technology can help provide the scaffolding for connectivist learning and as well as the channels for interacting with dynamic sources of data. For example, the AR game Electric Agents (Revelle et al. 2014) that enables learners to learn vocabulary by interacting with a TV show in which learners collaborate through a mobile augmented reality experience is an example of the use of Connectivism.

As mentioned, learning theories fall into one of learning paradigms. Here we briefly describe each learning theory or models within each paradigm.

1.2.1 Models and Theories for Behaviourism and Cognitivism

Sign learning model presents learning as the acquisition of knowledge through meaningful behaviours (Tolman 1922). **Brain-based learning** model presents learning as a cognitive development process, which emphasises how people learn differently as they grow, mature socially and emotionally and cognitively (Jensen 2008).

1.2.2 Models and Theories for Constructivism

According to **contextual learning** theory learning occurs only when students process new information or knowledge in such a way that it makes sense to them in their own frames of reference (their own inner worlds of memory, experience and response) (Wikiversity 2017) (as in the AR game titled Astrid's steps (Nilsson et al. 2012)) while **situated learning** theory argues that learning is not transmission of abstract and contextualised knowledge between individuals, but a social process within certain conditions, which include activity, context and culture (Anderson et al. 1996) (as in the games Outbreak (Rosenbaum et al. 2007), Mad city Mystery (Squire and Jan 2007), and EcoMOBILE (Kamarainen et al. 2013)). The basic principle of **scaffold of learning** is that the teachers or the instructors provide the support and scaffolding for the learner until learners adapt the knowledge into their own cognitive structure (Math Solutions 2016) (as in the games AmonPlanet (Hodhod 2014), and Electric Agents (Revelle et al. 2014)). **Case-based learning** models introduce learners, who typically work in groups, to a hypothetical situation (case) they are likely to face in real life. They are then encouraged to examine and discuss it (Williams 2005). **Simulation-based learning** strategy provides learners with an experience of working on a simplified simulated world or system. This approach is widely adopted in military and aviation to maximise training safety and minimise risk (Lateef 2010). **Goal-based learning model** combines case-based learning with learning by doing and defines a set of steps needed in order to accomplish desired goals (Hubbard 2012) (as in the games Mystery at the Library (Fitz-Walter et al. 2012), and Hwang et al. (2016)). **Problem-based learning** approach suggests that learning is more effective when learners are faced with a real-life practical problem they need to solve and empowers learners to conduct research, integrate theory and practice and apply knowledge and skills to develop a viable solution to a defined problem (Savery and Duffy 1995) (as in the games Parallel (de Sainte-Foy 2015) and Leometry (Laine et al. 2016)). **Challenge-based learning** is similar to problem-based learning, but with this model, learners formulate their challenges (Wikipedia 2012) (as in the games PasswARG (Eishita et al. 2014), and UniRallye (Rogers et al. 2015)). In **inquiry-based learning** model, learners are encouraged to use real-world examples; inquiry represents questioning that forwards curiosity in learners (Wikipedia 2016a) (as in the game Environmental Detectives (Squire and Klopfer 2007)). **Incidental learning** model refers to the fact that people learn a lot without explicit intention to learn or without instruction, such as learning of new vocabulary through imitation and social interaction, learning social norms through playing games with other children, learning geography through travelling or surfing the web (Edutech Wiki 2016).

1.2.3 Models and Theories for Humanism

Experiential learning models define the process of learning as "learning through reflection on doing". According to the experiential learning model, knowledge results from the combination of grasping and transforming experience (Wikipedia 2016b) (as in the games Furio et al. (2013a) and Luostarinmäki Adventure (Viinikkala et al. 2014)). **Passion-based learning** model facilitates learning by harnessing and focusing on the learner's passions as well as creating passion within the learners (Brown 2006). In Table 1.1, we illustrate a brief comparison of learning paradigms including learning theories that fall into each based on Ashworth et al. (2004).

1.3 Games, Gamification and Game-Based Learning

In this section, we explore digital games and their genres. In the context of education, physical games have been used for years in the educator-centred setting where educators set up rules among students (Jan 2009).

One of the strengths of using games in learning is that it lays out situations that require reflection and decision making in order to solve problems. Unlike more traditional teaching methods, using games in teaching can acknowledge the capacity to capture the attention of students and ensure their full engagement. The motivating style of games turns the learning process into something dynamic and interesting, which is maintained as students' progress to achieve objectives. Besides motivation and a playful approach, learning through games allows students to experience things in non-threatening scenarios and acquire knowledge through practice and social interaction both with the environment and their peers (Pak 2011).

With the advancement of technology, digital games came to the forefront as well (Prensky 2004). Digital games present a structured interactive experience during which players must follow a set of rules and game stages to either achieve the aim of the game (win) or not (lose) (Schell 2014). Games are often classified into genres, which purport to define games in terms of having a common style or set of characteristics, such as gameplay, interaction, objective as given in Table 1.2. It needs to be stressed that other game genres might be found in the literature. However, we have based our analysis on Wikipedia (2014) since it covers all games in the analysed papers.

Different game genres can have different impacts on different learners. Some learners may best learn through puzzle games, based on their abilities to process information (i.e. logical thinking, memory, pattern matching, reaction time, etc.), while others may best learn through role playing or simulation games. Also, different game genres may appeal to different learning models. If games are used in the classroom or outside the classroom, the game genres should be selected to match the learning models (Rapeepisarn et al. 2008). Prensky (2003) emphasises activities and learning techniques used in educational games and discusses how to combine gameplay and

Table 1.1 Comparison of learning paradigms (Ashworth et al. 2004)

	Behaviourism	Cognitivism	Constructivism	Humanism	Connectivism
Timeline	Since 1900s	Since 1960s	Since 1960s	Since 1970s	Since 2000s
What is learning	Development of desired behaviour	Acquisition of new knowledge and developing adequate mental constructions	A mean which should help learner in self-actualization and development of personal potentials	Construction of new knowledge	Process of connection-forming
Control locus	Environment	Learner	Learner	Learner	Mostly learner but also environment
Role of learner	Passive, simply responding to external stimuli	Active and central to the process, he learns objective knowledge from external world	Active and discovery	Active, constructing his representation of knowledge using preferred learning styles	Knowledge acquisition in form of establishing connections to other nodes
Learning process	External supporting of desired or punishing of undesired behaviour	An active process of acquiring and processing new information using prior knowledge and experience	Active learning through experience	Construction of subjective representation of knowledge based on prior knowledge and experience	Learning can also reside outside a person (within a database or an organisation) and is focused on establishing connections

(continued)

Table 1.1 (continued)

	Behaviourism	Cognitivism	Constructivism	Humanism	Connectivism
Critics	Ignores learner and his mental processes, depends exclusively on obvious behaviour	Views knowledge as objective and external to the learner	More psychologically than experimentally grounded approach based on assumptions of free will and a system of human values which are generally believed to be true, yet sometimes discredited through counterexamples	There is little evidence for some constructivist views, and some even contradict known findings	A relatively new and according to some not fully developed theory
Learning theories and models	Sign learning	Brain-based learning	Situated learning contextual learning Scaffold of learning Collaborative learning Case-based learning Simulation-based learning Goal-based learning Problem-based learning Challenge-based learning Inquiry-based learning Incidental learning	Experiential learning Passion-based learning	

Table 1.2 Game genres (Wikipedia 2014)

Game genres	Description
Adventure games	Typically, the player is the hero of a story and in order to progress must solve riddles. The riddles can often involve manipulating and interacting with in-game objects, characters, etc.
Action games	Action games are represented by fast-paced events and movements, which often have to be performed reflexively
Simulation (immersive sim) games	Simulation games describe a diverse super-category of games, generally designed to closely simulate real-world activities
Puzzle games	Puzzle games often require the player to solve puzzles or problems and can involve the exercise of logic, memory, pattern matching, reaction time, etc.
Strategy games	Strategy games are typically defined by a number of goals around resource collection, base and unit construction and engagement in combat with other players or computer opponents who also share similar goals
Role playing games	Role playing games are often characterised in terms of providing the player with flexibility in terms of character development, problem resolution, etc.
Treasure hunt games	Treasure hunt games encourage the player to search for hidden objects by following a trail of clues
Serious games	Serious games aim to simulate physical activities such as flying an aircraft

learning. He claims that educators can choose different learning activities according to particular types of content and proposes the relationship between the learning content, learning activities and possible game style. Another research (Chong et al. 2005) shows the impact of learning styles on the effectiveness of games in education. The results show that the students' preferences of the games vary according to learning style. Furthermore, Rapeepisarn et al. (2008) propose a new conceptual model by comparing and matching learning styles, learning activities and game genres based on studies conducted by Prensky (2003) and Chong et al. (2005).

Besides distinguishing different game genres, it is also important to distinguish between already defined games, game-based learning and gamification. Game-based learning involves designing learning activities with game characteristics and game principles inherent within the learning activities themselves (Wikipedia 2014; Prensky 2003). Gamification, in contrast, is the integration of game principles and game design elements such as points, leader boards and badges into non-game contexts such as education and commerce, in order to increase engagement and motivation of the users (Deterding et al. 2011). While both, gamification and game-based learning, concepts promote engagement and sustained motivation in learning, the two have certain characteristics that make them unique (Karagiorgas and Niemann 2017). Table 1.3 shows the distinction between games, gamification, and game-based learning.

Table 1.3 Comparison of game, gamification and game-based learning

Game	Game-based learning	Gamification
The actual interactive experience May or may not enhance our present level of awareness or knowledge	Uses games to meet learning objectives Learning is achieved by playing the game	Uses gaming elements such as points, levels, achievements and badges to engage people People are motivated by external rewards

Hence, while games are for fun, game-based learning is a type of game play that has defined learning outcomes. Gamification, on the other hand, is more than simply adding games to learning objectives. It utilises the experience of fun along with intrinsic motivation and rewards to engage and captivate individual participants.

1.4 Method

In this section, we explain how we identified papers that describe AR games in educational settings. We conducted a systematic search of available literature on Google Scholar, IEEE Xplore and ACM Digital Library. We searched for the following keywords and their different combinations: "augmented reality", "education", "learning", "game-based learning", "gamification", "edutainment", "augmented reality games" and "AR games". Furthermore, we conducted a search on the education and game sections of Google Play,[1] Apple Store,[2] Steam[3] and Educational App Store.[4] We used keywords such as "educational AR", "cross-platform AR" and "learning games" to filter our search.

During the search process, we used inclusion and exclusion criteria defined upfront, which are presented in Table 1.4. In our search, we solely focused on papers reporting on AR games (either real games, applications supporting game-based learning or applications using gamification principles as described in the previous section) studied in the educational settings. Applications that were considered or described as fun but that did not use game mechanics were not included. We also excluded articles describing the implementation of AR games only. We did not include articles without any study as well as articles that reported a short/small pilot study without a description of the evaluation method(ology). Exceptionally, we included two studies (Santoso et al. 2012; Hodhod 2014) without a proper evaluation method as they were strongly designed upon both AR gaming and educational principles.

[1] Google Play https://play.google.com/.

[2] Apple Store https://www.apple.com/ios/app-store/.

[3] Steam https://store.steampowered.com/.